Critical success factors (CSFS) framework of architecture, engineering and construction (AEC) firms for delivering green building projects

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**CRITICAL SUCCESS FACTORS (CSFS) FRAMEWORK
OF ARCHITECTURE, ENGINEERING AND
CONSTRUCTION (AEC) FIRMS FOR DELIVERING
GREEN BUILDING PROJECTS**

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SCHOOL OF CIVIL & ENVIRONMENTAL
ENGINEERING
2012**

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GREEN BUILDING PROJECTS**

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LIST OF ABBREVIATIONS

AEC	Architecture/ Engineering/Construction
BEES	Building for Environmental and Economic Sustainability
BEST	Building Energy Standard
BCA	Building and Construction Authority
BOT	Build-Operate-Transfer
BREEAM	Building Research Establishment Environmental Assessment Method
C&D	Construction & Demolition
CRS	Contractors' Registry System
CSFs	Critical Success Factors
DB	Design-Build
ECO	Environmental Control Officer
EMS	Environmental Management System
GFA	Gross Floor Area
GMM	Green Mark Manager
GMP	Green Mark Professional
HDB	Housing and Development Board
ISO	International Organization for Standards
KMO	Kaiser-Meyer-Olkin
LCA	Life Cycle Analysis
LEED	Leadership in Energy and Environmental Design
MND	Ministry of National Development
NEA	National Environment Agency
PFI	Project Finance Initiative
RBV	Resource-Based View
R&D	Research & Development
SIA	Singapore Institute of Architects
SMEs	Small and Medium Enterprise
UNEP	United Nations Environment Programme
USGBC	United State Green Building Council
VOC	Volatile Organic Compounds
WCED	World Commission on Environment and Development

ABSTRACT

The building industry, which provides an indoor environment for people to live and work, has a significant impact on many of the environmental problems faced by our society. More and more experts and researchers attached great importance to Green Building, which can reduce environmental impacts, and improve working and living conditions. In the last few years, the Green Building market expanded rapidly and Green Building is gradually becoming a part of the mainstream building industry. Due to regulations and growing environmental awareness, Green Building is likely to become the norm and not the exception in the future. The Architecture/Engineering/Construction (AEC) firms, who are responsible to transform the conceptual ideas of Green Building into “constructed reality”, now face major challenges to deliver Green Building. However, since the concept of Green Building is relatively new, many AEC firms do not know how to design and construct buildings to improve the environmental performance and get the building to be certified by the national Green Building rating system.

The main objective of this research is to construct a conceptual model to help AEC firms and project team understand how to carry out Green Building projects. Based on analysis of the value chain and system frameworks for Green Building, an extension of Porter’s value chain and system models, Generic Revolution Model and Critical Success Factors (CSFs) Frameworks of AEC firms are developed in this study. Generic Revolution Model proposes that Green Building is dependent on not only Green Building measures, but also support management activities. However, not much work has been done to investigate critical management activities for Green Buildings. In this research work, Generic Critical Success Factors (CSFs) Framework of AEC Firm, which mainly focuses on support management activities, is created. It postulates that the success of a Green Building project is a function of project management factors, organizational factors and external relationships. The establishment of Generic Revolution Model and CSFs framework can help AEC firms understand how to maximize their contributions to Green Building projects effectively and efficiently.

The generic CSFs framework can be used as a framework to facilitate the identifying of critical management factors for a specific Green Building rating system. Since Green Mark has become the compulsory requirement for new constructions in Singapore, this study focuses on identifying specific critical management factors for Green Mark in Singapore. A structured questionnaire is developed to facilitate systematic data collection and 37 valid responses are obtained from experienced experts, who have been involved with Green Mark certified projects. Factor analysis and stepwise multiple regression analysis are then applied and a specific Critical Success Factors (CSFs) Framework of AEC firms towards Green Mark certified projects is established. Key findings indicate that two project management factors: “coordination of designers and contractors” and “technical and innovation-oriented factors”, strongly influence Green Mark certified projects. “Organizational culture”, “R&D capability”, “organizational structure”, “experience and knowledge in Green Building”, “innovation capability” and “technical competency” are found to be significant resources and abilities that AEC firms should cultivate in order to achieve higher rating of Green Mark. Furthermore, “clients”, “government”, “qualified/certified materials and products suppliers” and “good green consultants” are found to be the important external players who strongly contribute to Green Mark certified projects, and thus AEC firms should established strong relationships with them. Besides, three qualitative case studies were conducted. The results not only validated the CSFs framework but also provided an in-depth look into why these factors important and how the AEC companies improved these factors.

To sum up, the Generic Revolution Model and CSFs framework provide valuable important activities in the implementation of Green Building projects and the specific CSFs framework provides the critical management factors of AEC firms for delivering Green Mark certified projects. The findings in this study will enhance the understanding of contractors and designers on how to run a successful Green Building project, especially in Singapore and help project participates allocate limited resources effectively and efficiently. Besides, this research will also enrich the body of knowledge in projects management.

Keywords: Singapore, Construction industry, Architecture/ Engineering/Construction (AEC) firms, Green Building, Green Mark, Critical success factors (CSFs)

Chapter 1 Introduction

1.1 Introduction

In this chapter, the research background and research gaps in the area of Green Building are discussed. The research objectives that can fulfill the research gaps in this field are established. Finally, the outline of the thesis is presented.

1.2 Research Background

Buildings (mainly including residential, commercial and office buildings) are significant part of our everyday life and are the key ingredient that distinguishes one city from another. The building industry also plays a vital role to the development of national and global economy. However, the building activities can have seriously negative environmental impacts; for instance, construction and demolition waste generation are the major direct and indirect contributors to the environmental problems faced by our society. The growing pressure for environmental sustainability increases the need for stakeholders to take responsibilities to minimize negative environmental and social impacts. Therefore, “Green Building” is gaining greater attention in the last decades. Green Building is the practice of creating and using healthier and more resource-efficient models of construction, renovation, operation, maintenance and demolition (USGBC, 2007). It aims to reduce environmental impacts, improve working and living conditions, and provide cost saving opportunities in operations. In the last few years, the Green Building market expanded rapidly and Green Building is gradually becoming a part of the mainstream in construction industry. Due to regulations and growing environmental awareness, Green Building is likely to become the norm in the future.

In order to reduce environmental pollutions, measures should be taken throughout all life cycle stages of building projects. Cheng (2001) defines Green Building as “any building that is sited, designed, constructed, operated, and maintained for the health

and well-being of the occupants, while minimizing the impact on the environment”. However, it is the Architecture/Engineering/Construction (AEC) firms that transform the conceptual ideas of clients into “constructed reality”, and the decisions made at the phases of building design and construction can significantly affect the environmental performance of building projects. The U.S. Green Building Council, creators of the Leadership in Energy and Environmental Design (LEED) “green” commercial building program, defined Green Building as the “design and construction practices that significantly reduce or eliminate the negative impacts of buildings on the environment and occupants” (USGBC, 2003). This definition emphasizes the importance of the design and construction stages to improve environmental performance of building projects. Therefore, more efforts should be devoted to AEC firms, who are the main players in the design and construction stages of Green Building projects. At present, AEC firms face major challenges caused by increasingly restrictive laws and regulations to improve the environmental performance. For example, Green Building has now become a compulsory requirement in Singapore, which places a greater responsibility on AEC firms. Therefore, research work should focus on the role of AEC firms in the implementation of Green Building projects.

1.3 Problem Statement

The process of delivering Green Building projects is more difficult than that for traditional building projects. It requires AEC firms to make significant changes to the way they currently design and construct buildings. However, since the concept of Green Building is still relatively new, many AEC firms have little experience on how best to design and construct such buildings and get the required certification from the corresponding building authority.

Till now, many technologies, products and Green Building measures have been developed (for example green roof, advanced simulation and analysis tools, and new and unfamiliar recycled materials), and some of them have been applied in the

building industry during the design and construction stages. A few AEC firms, who have been involved in Green Building projects in practice, become more adept in understanding these measures required for Green Building projects. However, integrating the numerous measures into building design and construction can be a daunting process. Besides the technical issues, the non-technical aspects are equally important for successful implementation of Green Building measures. It is widely believed that the management is the primary factor that determines the success or failure of a project (Imada, 2002). However, the current construction management approach does not align with the sustainability goal (Sharon, 2002). It can result in actions that encourage environmental destruction, poor quality control, and wasteful behavior (Imada, 2002). Therefore, in order to construct Green Buildings, there is a need for changes in the way construction projects are managed. However, previous studies mainly focus on technical methods and engineering procedures, with less consideration given to the management process. Therefore, how to effectively adopt these technical solutions and maximize sustainability efficiently will be an important research agenda.

Furthermore, there is a lack of methodology that can assist the AEC firms in identifying the management practices to deliver Green Building projects. A large body of research suggests that many of the reasons behind project success can be found in the existence of Critical Success Factors (CSFs) (Pinto and Covin, 1989) and comprehensive analysis of CSFs can help AEC firms to maximize their contributions to Green Building projects effectively and efficiently. The CSFs approach has been established and popularized over the last 20 years and CSFs for the project success have been widely investigated. However, the majority of the studies mainly focus on the cost, quality and schedule of projects and there exists a research gap that focuses on sustainability of buildings.

1.4 Research Objectives

The main objective of this research is to construct a conceptual model to help AEC

firms and project team understand how to deliver Green Building projects effectively. The model should connect the conventional organizational management practices and environmental performance of building projects.

In order to realize the objective, this research poses the following questions:

- 1) What activities should be carried out by AEC firms to be capable to undertake Green Building projects?
- 2) What are the potentially important managerial factors within the control of AEC firms that contribute to the successful delivery of Green Building projects, and how to explore these factors comprehensively and systematically?

In order to answer the aforementioned questions, the following research works will be carried out:

- 1) Develop a Generic Revolution Model to provide a roadmap for AEC firms in undertaking Green Building projects.
- 2) Formulate value chain and system frameworks for Green Building, which is an extension of Porter's value chain and system models. It serves to frame issues and help explore the managerial factors within the control of AEC firms for delivering Green Building projects.
- 3) Establish a Generic Critical Success Factors (CSFs) Framework of AEC firms to help project participants improve environmental performance of building projects.

The generic conceptual model can be used as guide to facilitate the identifying of critical management factors for a specific Green Building rating system. There are several Green Building rating systems in use globally. Singapore's Green Mark has become the compulsory requirement for new buildings since 2008. This requirement places a greater pressure on AEC firms. Besides, Green Mark is a relatively new requirement and most AEC firms in Singapore do not have adequate experience on how to achieve Green Mark certification effectively. Therefore, this study focuses on identifying specific critical management factors for Green Mark certified projects in Singapore, as the specific objective of this study. There are difference kinds of

buildings in Singapore, in this research, only new residential, commercial and office buildings, which is the main part of construction industry, are considered.

1.5 Outline of the Thesis

The rest of this thesis is organized as follows:

Chapter 2 Literature Review

Chapter 2 reviews existing literature on Green Buildings. This chapter also reviews previous efforts and findings on CSFs methodology and summarizes the major directions in this area. Since this study examines how the proposed generic conceptual framework can be applied in this specific context of Green Mark, the current practices for the development of Green Building in Singapore are discussed. Based on the literature review, the deficiencies of previous studies are identified.

Chapter 3 Research Methodology

Chapter 3 describes the methodologies adopted in this study. It explains the data collection process, including literature review on CSFs, pilot study, and questionnaire survey. Then, the data distribution strategy is introduced. Finally, the data analysis methods are discussed. Based on these methodologies, the research objectives can be realized.

Chapter 4 Generic Revolution Model and Critical Success Factors Framework for AEC Firms towards Green Building Projects

In this chapter, a Generic Revolution Model of AEC firms for delivering Green Building is developed based on an analysis of the value chain and system frameworks for Green Building, which are extensions of Porter's value chain and system models. Additionally, a proposed Critical Success Factors (CSFs) Framework, which comprehensively summarizes the factors within control of AEC firms that have a potential effect on environmental performance of building projects, is established. These factors are classified under the following categories: organizational factors, project management factors and external relationships. However, the identification of

these critical management factors in this chapter is considered from a theoretical point of view. To examine the application of the generic framework, further empirical studies for exploring the relative importance of these management factors for achieving Green Mark certification will be done in Chapter 5 and Chapter 6.

Chapter 5 Research Findings and Discussion

Chapter 5 presents statistical analyses of the research data collected from the questionnaire survey conducted in Singapore as well as discussion of research findings. Firstly, the general information of the survey is presented. Then, major research variables listed in the CSFs Framework are interpreted. Subsequently, the relative significance between all the factors is measured by factor analysis and stepwise multiple regression analysis. Finally, the results are discussed and the revised CSFs framework for Green Mark certified project is generated.

Chapter 6 Case Studies

Chapter 6 provides three detailed case studies. The purpose of case studies is to illustrate the findings from the survey, and reinforce why these factors are important to improve environmental performance and how to perform well in these factors to score more Green Mark points efficiently and effectively.

Chapter 7 Conclusions

In Chapter 7, the overall conclusions of the research study are presented. The major contributions and research limitations are also discussed. Finally, the potential areas for future research work are identified.

Reference and appendices are also included at the end of this thesis.

Chapter 2 Literature Review

2.1 Introduction

This chapter is organized as follows. First, an outline of the worldwide development of Green Building is presented. Secondly, various contemporary and previous research papers on Critical Success Factors (CSFs) methodology are summarized. Finally, since this study focuses on Singapore's Green Mark, the development of Green Building in Singapore is reviewed. The gap in the existing literature in the context of Green Building is then identified.

2.2 Current Development of Green Building

In this section, major development practices of Green Building are summarized. Then, the research works that focus on Architecture/Engineering/Construction (AEC) firms towards Green Building are also reviewed.

2.2.1. Negative Environmental Impacts of Building Industry

Construction is the building or assembly of any infrastructure (Alnaser and Flanagan, 2007). The building industry, which provides an indoor environment for people to live and work, is a major component of construction industry. In recent years, the building industry attracts growing concern because of the environmental pollution and hazards that they could cause. It is responsible for high energy consumption, solid waste generation, global greenhouse gas emissions, external and internal pollution, environmental damage, and resource depletion (CICA, 2002; Zimmermann *et al.*, 2005; Melcher, 2007; Ortiz *et al.*, 2009). According to Jasbir (2006), buildings account for: 40% of the raw stone, gravel, and sand used globally each year, 25% of the raw timbers, 40% of energy, 16% of world's freshwater withdrawals, 25% of all ozone-depleting Chlorofluorocarbon, 35% of world's CO₂ emissions, 40% of solid waste, 10% of particulate emission, 25% of Nitrous Oxide emission, and 70% of the sulphur dioxides produced by fossil fuel combustion are produced through the

creation of electricity used to power houses and office.

Negative environmental impacts caused by these activities range from effects at a local level (landfill problems, unhealthy indoor air quality and heat island phenomenon) to regional and global effects (global climatic change, ozone depletion and acid precipitation). The building industry also cause health and safety problems to construction workers, who are frequently exposed to many hazardous materials and practices. Tibbetts (2002) stated: “Drillers, sandblasters, drywall sanders, and brick masons risk inhaling particles of dust, sand, and crystalline silica, which can lead to lung cancers, tuberculosis, and silicosis. Asphalt used in paving and roofing has been linked to throat irritation, nausea, and chronic lower respiratory infections. Workers doing finishing work breathe in toxic fumes from paints, adhesives, floor finishes, and other materials. And renovation and demolition can expose workers to lead paint, asbestos, and toxic molds”.

Because of the building industry’s irreversible impacts on the environment, even modest changes that promote resource efficiency in building construction and operations can make major contributions to environmental performance (Sadiq, 2005). Therefore, the building industry has been urged by regulating bodies, environmental interest groups, and “green” societies to minimize its impacts on the natural environment (Fee, 2006).

2.2.2. The Definition of Green Building

A Green Building is a design which performs more efficiently than traditionally designed buildings in methods of building construction, materials utilized during construction, building functionality and system performance, energy and water efficiency, quality of the indoor environment (air quality, thermal comfort, lighting), waste management and air emissions, site disturbance and storm water management, transportation options for occupants and longevity (durability, adaptability to changing user needs) (Paumgarten, 2003). The application of Green Building principles offers an approach in reducing environmental degradation (Eno, 2005).

The history of Green Building can be traced back to the early 1970s during the energy crisis that was initiated by oil embargo. Therefore, the early concern of Green Building was energy consumption. However, the definition of Green Building has been updated to cover much broader connotations in recent years. Other terminologies that can be used interchangeably include: sustainable building, high performance building, environmental building and ecological building. Other definitions are closely related to sustainable development. For example, Burt (2002) defined sustainable construction as “those materials and methods used to construct and maintain a structure that meets the needs of the present without compromising the ability of future generations to meet their own needs”. This definition is in line with that of sustainable development given by the United Nations’ Bruntland Commission (WCED, 1987): “Development which meets the needs of the present without compromising the ability of future generations to meet their own needs”. Some definitions focus on the approaches to achieve Green Building. Loken (1999) stated that a Green Building involves the “appropriate use of technology and resources”. However it is not merely a component-by-component substitution for traditional building products, but it is instead, a “whole-building” approach to design (Bynum, 1999). Similarly, the U.S. Green Building Council (USGBC, 2001) defined Green Building design or development as “a process to design the built environment while considering environmental responsiveness, resource efficiency, and cultural and community sensitivity”. This concept also emphasized that “the process includes all players in the building design, from the design team (building owners, architects, engineers, and consultants), the construction team (materials manufacturers, contractors, and waste haulers), to maintenance staff and building occupants”.

In recent years, a large number of literatures on Green Building have been published. However, due to the broad range of issues associated with sustainability, many different definitions of Green Building have been put forth and there is little consensus for its definition.

2.2.3. Benefits of Green Building

Green Building can result in a triple bottom line - offering environmental, social, and quantifiable financial benefits (Griffin, 2005). Among the benefits, the environmental impacts are very obvious, because most of environmental benefits are measurable, quantifiable and well documented. For example, TerraLogos (2001) reported that Green Buildings use only two-third of the energy and half of the water of comparable standard construction. In addition, they use 20% less materials, 40% more recycled components, and send 35% less Construction & Demolition (C&D) waste to the landfill. Similar findings are also observed by Rodman and Lensen (1996): as much as 60% of the heating and cooling energy and 50% of the lighting energy consumed by U.S. buildings can be saved by using climate-sensitive design and available technologies. Water-efficient appliances and fixtures, behavioral changes and changes in irrigation methods can reduce consumption by 30% or more (Abraham *et al.*, 1996). Efficient use of recyclable materials such as gypsum, glass, carpet, aluminum, steel, brick and recycling of debris can achieve considerable waste reduction (Sadiq, 2005).

In addition to environmental protection, a number of research works has been conducted to study the social benefits of Green Building. Some of the measures that can help improve indoor air quality are: selecting Green Building materials which have low Volatile Organic Compounds (VOC) emission, the use of integrated ventilation systems and effective building envelopes and efficient management during construction or renovation (Sadiq, 2005). On average people spend more than 90% of their time indoors, and indoor air quality plays an important role for the health, comfort and even the productivity of the occupants. Recent extensive research conducted by Kumar and Fisk (2002) and Heerwagen (2002) identified strong correlations between sustainable design features (e.g. natural lighting, thermal comfort, air quality, worker-controlled temperature and ventilation, etc.) and reduced illness symptoms, reduced absenteeism and increase in productivity of workforce. Studies conducted by Romm (1994) had also shown that buildings with good overall

environmental quality, including effective ventilation, natural or proper levels of lighting, indoor air quality, and good acoustics, can increase worker productivity by 6% to 16%. Besides, natural daylighting improves learning efficiency in schools, increases sales in retail environments and helps the elderly in retirement homes sleep better and live longer. In hospital, people recover faster when they have access to daylight (Hitchcock and Willard, 2007).

Although environmental and social benefits of Green Buildings are widely accepted, cost is still a prohibitive factor to integrate Green Building practices into projects. It has been reported that many businesses now understand that socially and environmentally responsible practices can provide long-term economic benefits (Shiers *et al.*, 2007). For example, using less energy and water lessens not only a building's environmental impact, but also its operating costs (Griffin, 2005). Occupants' benefit from health and safety features also relates to risk management and economics (Liu, 2005). Kats *et al.* (2003) conducted that the total financial benefits of Green Building are over ten times the average initial investment required to design and construct a Green Building.

2.2.4. Barriers to Implement Green Building

Due to the negative environmental impacts of buildings, there has been increasing pressure on the building industry to take a more responsible attitude towards the environment. Until now, many energy and pollution reduction technologies have been developed. Several sustainable products and materials are currently in use in the marketplace. A wide variety of Green Building and Life Cycle Analysis (LCA) tools can be used for altering building designs and construction processes. The advancement of sustainable technology and tools provide a foundation for the development of Green Building and make the improvement of environmental performance of buildings possible. Unfortunately, the progress in the practice of Green Building is still slow, especially in developing countries. Based on the literature, barriers to implementing Green Building are outlined in the rest of this section.

1) A contested concept

There is no consensus on the meaning of “sustainable” and how to achieve a Green Building. Most seem to be in favor of this goal, but it is very difficult to implement tangible policies and objectives to achieve it. As far as building design is concerned, few designers are assertive about what exactly needs to be done, or even where to start, to practically achieve sustainability (Xun, 2005). They do not even have a system in place to evaluate whether the goals have been met or not.

2) Delay between cause and effect

The delay between the cause or “upstream” activities (for instance, use of Chlorofluorocarbon) and the observed effect in carefully investigated and defined “downstream” symptoms (for instance, various symptoms resulting from increased ultraviolet radiation), may sometimes be several decades (Henrik, 2000). The delay makes it difficult for people to identify the consequences of decisions and actions. That partly explains why the decision-makers are not under pressure to take responsibility for those consequences. Furthermore, this lapse is also because the results are not proportionate to the individuals’ behavior (Eno, 2005).

3) Durability of buildings

The long life of buildings makes it difficult for the cooperation of various stakeholders. For example, the issues relating to the reusability and recyclability of building materials after the buildings’ useful life are remote considerations for the choice of building materials at the design stage. Furthermore, due to the long lifespan of buildings, many different owners may reside in the building. Most buyers do not have the benefit of experience from repeated transactions in the property market. As a result, this benefit does not generally translate to a higher price for the property. Therefore, landlords or developers have inadequate incentives to invest in environmental improvements.

4) Complexity and fragmentation

Generally, a large number of players are required to accomplish the necessary tasks

for projects such as designers, constructors, financiers, clients, and many other diverse constituents. This complexity results in high fragmentation of the building industry because it involves many workers with different roles in creating the final product (Fee, 2006). The fragmentation of the building industry limits widespread acceptance and utilization of new sustainable practices on several levels. It also makes collecting data from the industry's constituents challenging (Fee, 2006).

5) Lack of awareness

Not all industry players are aware of the importance of Green Building and some have misconceptions about it. One important misconception that prevents many decision-makers from pursuing sustainability is the assumption that Green Buildings are a lot more expensive than conventional buildings and often not worth the extra cost. However, there are numerous examples of Green Buildings not costing more (Griffin, 2005). For example, Matthiessen and Morris (2003), found that many building projects can achieve with a small supplemental funding (3% of initial budget), substantially lower than what is commonly perceived. Even if there is an increase in construction costs to go green versus conventional buildings, those costs can usually be recovered quickly through savings in operational costs by cutting down energy waste and recycling materials (Paramanathan, 2004). Therefore, if one considers the entire life-cycle costs, the financial advantages of Green Building become more apparent.

6) Lack of policy or legislation

Support is required from the government agencies or building authorities in the form of appropriate regulation, financial incentives, training support, reduction in taxes, easier governmental approvals for permits, low interest loans and also mentoring or role modeling (Boyle, 2002). However, there is a substantial statutory barrier to progress in the sustainability of buildings (Wetherill *et al.*, 2007). Although some local and national governments provide appropriate regulations, most of the regulations and codes of practice are prescription-based rather than

performance-based, which do not provide incentives for innovation and for the diffusion of sustainable innovations. For example, in Singapore the regulation states sunshades and overhangs should be incorporated into building façade in newer public flats, which may restrict the application of other innovative energy saving features.

7) Lack of leadership

National governments should guide society towards a sustainable built environment. Since many government buildings are owner-occupied, the little extra for “green” features can be recovered over the long term (Hitchcock and Willard, 2007). Government could set an example for other organizations by adopting green procurement policy (Buerena and Jongb, 2007). Unfortunately, few government do so.

8) Lack of willing suppliers

Builders commented that the greatest improvements in green participation can be easily achieved if suppliers are convinced of the benefits caused by producing environmental goods and start offering more options and better prices for them (Tinker, 2003). However, in most countries, the markets for sustainable products and materials are not fully developed. Many products such as non-ureaformaldehyde particleboard, recycled carpet, and 100% recycled sheetrock, are not cost-neutral and are not commonly available. This urgently requires coordinating the construction supply chain to improve environmental performance.

9) Lack of financing

Capital cost is one of the factors that limit the inclusion of many Green Building measures in conventional building design. Some green features that are expected to have significant environmental impacts may not be implemented simply because they cost more upfront; for example rainwater collection systems, solar heating and photovoltaics. Notwithstanding the savings over the life cycle, many normal building stakeholders do not have enough funds to implement Green Building. Moore (1994) stated that “inadequate funds to support the implementation of environmental initiatives can prevent their realization.” Kats *et al.* (2003) also recognized that “the

cost issue was becoming more and more of a prohibitive factor in the mainstreaming of Green Building”.

10) Contract barriers

Successful Green Building design and construction processes are characterized as collaborative and interdisciplinary (Griffin, 2005). However, the traditional procurement process is often compartmentalized, with each element of the built environment and civil infrastructure development process (planning, management, design, construction, operation, etc.) conducted by a different party under a separate contract (Hartshorn *et al.*, 2005). The rigidity of the contract can often hinder the communication behavior of the project parties.

11) Lack of knowledge

Many actors involved in building projects are often unfamiliar with environmental friendly materials and technologies; or they do not know how to implement them, or how to organize and manage the collaboration at various stages of the building process. Coleman (2000) also stated that “76% of the designers surveyed categorize the lack of consistent and credible information about sustainable products and solutions as a key obstacle in embracing sustainable practices”.

2.2.5. Evaluation and Assessment Tools

Until now, a wide variety of Green Building assessment and evaluation tools have been developed and applied in practice. According to Trusty (2000), these assessment and evaluation tools can be classified into 3 levels.

Level 1 product comparison tools

Building for Environmental and Economic Sustainability (BEES)¹, the Environmental Resource Guide (ERG)², and SimaPro³ can be classified as Level 1. This level is used

¹ BEES software is a powerful technique for balancing the environmental and economic performance of building products. It can be used to select cost-effective green building products.

² ERG can provide information on the environmental aspects of building materials based on a life-cycle analysis of materials that spans manufacturing, installation and use in buildings, and reuse, recycling, or disposal.

primarily at the procurement stage. It may include economic as well as environmental or other data, and may have LCA in the background (e.g. BEES). They can be valuable for building databases and for making comparisons and choices at the procurement stage (Trusty, 2000).

Level 2 Whole building decision support tools

ATHENA⁴, Eco Quantum⁵, Envest⁶ and Radiance⁷, are classified as Level 2. Level 2 tools typically focus on a specific area of concern, such as life cycle costs, life cycle environmental effects, lighting, or operating energy, and a few combine more than one of these areas. Level 2 tools are uniformly data-oriented and objective, and typically intended for use by design team members. They may involve weighting or scoring, and all of the tools can provide important inputs to Level 3 tools (Trusty, 2000).

Level 3 Whole building assessment frameworks or systems

Building Research Establishment Environmental Assessment Method (BREEAM, UK), Leadership in Energy and Environmental Design (LEED, US), Green Building Tool (GBTool), EcoEffect (Sweden), EcoProfile (Norway) and Green Mark (Singapore) are classified in this typology. Generally, many countries have developed or are developing their own building assessment and rating systems. Some widely used assessment systems are introduced as follows:

Building Research Establishment Environmental Assessment Method (BREEAM) was developed by the Building Research Establishment in 1990 in UK. It is the first environmental assessment tool used internationally. BREEAM is a voluntary

³ SimaPro is used to model products and systems from a life cycle perspective. It can be applied for a variety of applications, such as carbon footprint calculation, product design and eco-design and environmental product declarations.

⁴ Athena mainly includes two types of LCA design tools: the Impact Estimator and the EcoCalculator. They are especially useful early in the design process when material choices have far-reaching implications for overall environmental impact in North America.

⁵ Eco Quantum is a computer tool on the basis of LCA which calculates the environmental effects during the entire life cycle of the building: from the moment the raw materials are extracted, via production, building and use, to the final demolition or reuse.

⁶ Envest predicts the environmental and cost impact of various strategies for heating, cooling and operating a building, allowing both environmental and financial tradeoffs to be made explicit in the design process.

⁷ Radiance is a daylight modeling program used by architects and engineers to predict illumination, visual quality and appearance of innovative design spaces.

evaluation program used to assess a building's performance based on the following areas: management, energy use, health and well being, pollution, transport, land use, ecology, materials, and water. Credits are assigned to those performance areas and weighted to take into account the importance of that issue in the overall environmental impact of a building. An overall score is determined and the building is rated as pass, good, very good, or excellent in terms of performance. The building assessment procedure and final score are completed and determined by a licensed BREEAM assessor (Kimberly *et al.*, 2006). BREEAM has also been used as a basis for similar programs in New Zealand, Australia, Hong Kong and Canada (USGBC, 2003).

Leadership in Energy and Environmental Design (LEED) is a design supporting tool and product marketing tool launched by the U.S. Green Building Council (USGBC) in 2000 in the United States. It is mainly used for the assessment of commercial and high-rise residential new constructions and major renovation. Professionals involved in the design and construction of a building may apply for LEED certification. There are four levels of certification: Certified, Silver Certified, Gold Certified, and Platinum Certified. The credits cover five categories: sustainable site development; water efficiency; energy efficiency; indoor environmental quality; reduced consumption of building materials.

Green Building Tool (GBTool) is a product produced by Green Building Challenge (GBC) in 1998 and is currently managed by the International Initiative for a Sustainable Built Environment (IISBE). Assessments of green performance are made in the following categories: resource consumption, loadings, indoor environmental quality, quality of service, economics, and pre-operations management. The method places emphasis on the ability of local users, and adapts the system to suit regional technical and cultural issues by enabling national teams to adjust values and weightings (Chang, 2007).

EcoEffect was developed by a group of researchers in Sweden to assess environmental impacts (Glaumann and Malmqvist, 2007). It is useful in the

assessment of existing buildings as well as new buildings at the program and design phase and intends to cover the full range of environmental issues by considering five separate areas at the same time: Materials use, Energy use, Indoor environment, Outdoor environment and Lifecycle costs (Ulla and Rolf, 2008).

Norway's EcoProfile system for commercial buildings has been in the market since 1999 (Todd *et al.*, 2001). It evaluated the building mainly in three performance areas: "external environment", "resources" and "indoor climate".

ESCALE was initially developed through a PhD thesis developed in CSTB (Centre Scientifique et Technique du Bâtiment) and the University of Savoie in France (Todd *et al.*, 2001). The assessment criteria of this program include: energy resources; water and materials resources; waste (construction, operation, demolition); large scale pollution (greenhouse effect, acid rain, ozone depletion, radioactive waste); local pollution (air, water, soil); contextual fit (landscape and architectural integration, respect for neighbours, outdoor comfort, site ecology, adaptation to networks); comfort (thermal, visual, acoustic, olfactive); health (indoor air quality, water quality); environmental management; and indirect criteria (maintenance, adaptability) (Todd *et al.*, 2001).

Hong Kong Building Environmental Assessment Method (HK-BEAM) was launched in December 1996. HK-BEAM assessment methods are available for existing office building projects and new residential building projects. The performance criteria include site development, materials use, indoor environmental quality, water use, and energy use, with the weighting for energy and emissions comprising about 30% of the total assessment score. The percentage grading system is: Platinum; Gold; Silver; Bronze.

These tools provide a very broad coverage of environmental, economic, social and other issues deemed to be relevant to sustainability. They use a mix of objective and subjective data, often relying on Level 2 tools for the objective data. Most use

subjective scoring or weighting systems to distil the information and provide some useable overall measures. Level 3 tools require external auditors, and most yield certifications or labels indicating a building's performance. The benefit of these systems is that their criteria is succinctly defined and is based on existing technologies and practice (Hanby, 2004). However, more accurate and comprehensive assessment tools will be developed due to the growing interest in sustainability. For example, a more systematic and comprehensive technology-evaluation framework has been brought forth by Nelms (2005). This framework can help assess the technologies from an environmental, social, economic, and technical perspective. It will improve the understanding and decision-making capabilities of the building industry and government when faced with decisions regarding investment and policy regarding Green Building technologies.

2.2.6. Involvement of AEC Firms towards Green Building

AEC firms, who transform the conceptual ideas of clients into “constructed reality”, make significant contributions to protecting the environment. Currently, most of the research works focus on the roles of AEC firms and to identify the main forces driving AEC firms to reduce the environmental impacts and their move towards Green Building.

2.2.6.1. Why Focus on AEC Firms

Construction is a multi-organization process, which includes the participation of client/owner, designer, contractor, supplier, and consultant. It is also a multi-stage process including conceptual, design, construction, maintenance, replacement, and decommission (Xue *et al.*, 2007). To achieve sustainability within the building industry, a broader life cycle perspective should be used (from a structure's conception to the end of its service life, and from raw material extraction to a building's demolition or dismantling). All actors, from land-use planners and property developers through building owners and users to salvage firms and landfill operators,

should be taken into account (UNEP, 2003a). Among them, the Architecture/Engineering/Construction (AEC) firms, including design and construction functions, play a critical role in environmental performance of building projects.

The design stage affords significant opportunities for influencing project sustainability, since buildings are the end product of all the design decisions taken at the design process (Malik, 2001). Specific elements considered in this phase include sustainable site development, integrated building systems design, energy and water efficiency, sustainable material use, and indoor environmental quality (Vanegas, 2003). For example, the choices of materials and their applications have a significant environmental impact, depending on the sources of materials, their durability, and potential reuse (Malik, 2001). Simply making buildings the right shape and the correct orientation can reduce the energy consumption by 30-40% at no extra cost (Zukowski, 2005).

In the construction stage, the contractor only needs to follow detailed specifications to meet sustainable requirements set at the design stage. Therefore, Green Building measures in this stage are often ignored. In fact, contractors play essential roles in Green Building projects (UNEP, 2003b). The recommendations, offering opportunities for increasing sustainability of projects, include erosion and sediment control, the choice of Green Building materials, sequencing work to minimize exposure of materials to potential contamination, waste minimization and recycling, commissioning, etc. (UNEP, 2003b; Syal *et al.*, 2007).

2.2.6.2. Driving Forces for AEC Firms towards Green Building

The development of Green Building is still in an early stage. The drivers for AEC firms to adopt sustainability principles is one of the main research topics in recent years. The drivers can be mainly classified into two categories: external and internal driving forces.

(1) External driving forces

External driving force means the force comes from external environment, for example from compulsory requirements enacted by government or demanded by clients. It forces the AEC firms to implement Green Building whether they are willing to do it or not. Some common external driving forces are discussed in detail as follow.

Regulations

Legislation is a key driver, which represents pressure from the government (Betz, 1998). In order to avoid adverse impacts on the environment, different kinds of regulations and restrictions have been formulated and implemented (Ngowi, 2001). For example, some area governments in European countries have outlawed construction waste from entering their landfills. AEC firms, facing increasingly restrictive environmental protection laws and regulations, have to incorporate sustainable practices into their construction activities-whether they want to or not, even in non-environmental projects.

Competition

In recent years, the competition in the building industry is very serious and many AEC firms are faced with challenges for survival. Green Building, as a new potential market in the near future, has created numerous challenges as well as opportunities for AEC firms. Already, owners seeking construction services on green projects are differentiating between prospective builders based on their environmental policies and experience in Green Building (UNEP, 2003b). Achieving Green Building certification can help AEC firms create a competitive advantage and increase their market share. The future success of companies within the construction industry may reveal itself to be partially dependent upon a company's willingness to incorporate sustainability into its practices. Therefore, competitive pressures alone are driving more firms toward Green Building projects, even if some of their principles are not really "believers" in sustainable design (Yudelsohn, 2007).

Market demand

The market is demanding Green Buildings mainly for three reasons: firstly, Green Building offers improved indoor air quality. People on average spend more than 90% of their time indoors, and indoor air quality plays an important role for the health, comfort and even the productivity of the occupants (Griffin, 2005). Secondly, the environmental benefits of Green Building are attracting more public attention due to their growing awareness of carbon dioxide emissions and global warming. Thirdly, Green Buildings offer lower future utility bills and other operating costs. Owners, therefore, can apply the lifetime savings of the building to construction costs (ECONorthwest, 2001; Griffin, 2005). Many surveys have shown the interests of consumers, for example, Johnston (1999) strongly suggested that the public's interest in environmental issues and corporate responsibility is on the rise and the American public ranks environmental issues as the number two area that business should work hardest to resolve. Green Building is not simply a fad. As owners continue to realize its benefits, demand for Green Building will continue to increase. These demands and expectations from the clients are driving the AEC firms to produce buildings that are environmentally friendly.

(2) Internal driving forces

Internal driving force means the force comes from AEC firms' internal needs. Green Building can bring extensive long term or short term benefits to AEC firms; therefore, they have great interests for delivering Green Building projects. The main internal forces for AEC firms are discussed as follows.

Business benefits

There is plenty of literature giving hints that business reasons are important for making the Green Building market attractive for AEC firms (Church, 1994; Golove and Eto, 1996; Meyers, 1998; Melet, 1999; Jiang, 2007; Qian and Chan, 2008). Firstly, many AEC firms perceive the environment as a business opportunity for improving their corporate image (Chung and Gillespie, 1998). For instance, a survey conducted

by Cassidy (2004) revealed that 72% of contractors felt that Construction & Demolition (C&D) recycling improved their company's public image. Secondly, good environmental performance can also enhance the competitive advantage of a company (Stigson, 1998). Thirdly, AEC firms participating in Green Building projects may enjoy improved relations with local government officials, who control zoning, construction permitting and building codes (Cassidy, 2004). Fourthly, many organizations agree that employees are their main assets, retaining them and the ability to hire quality recruits are crucial (Paramanathan, 2004). Companies that embrace the future trends of the building industry, namely the Green Building movement, are likely to attract quality employees (Griffin, 2005). Finally, technology and innovation skills can also be increased through the introduction of eco-efficient product designs (Paramanathan, 2004). Faced with the numerous business benefits, implementing Green Building projects have become part of many AEC firms' long term strategic planning for sustainable development. For example, forward-thinking company, Skanska, one of the world's largest construction companies, has incorporated sustainability in its business practices. Skanska is listed on the Dow Jones Sustainability Index for responsible investing, and in 2004 ranked third in the world on Fortune's list of Most Admired Companies for engineering and construction (Wenblad, 2003).

Economic benefits

Simple and effective environmental practices can deliver sound economic benefits not only to the buyers or consumers but also to AEC firms (Chan *et al.*, 2009). Financial gains for AEC firms mainly stem from savings in operational costs by cutting down energy waste and reducing the burden of environmental problems (Paramanathan, 2004). The most powerful example of sustainable practices increasing contractors' profits is that waste management plans can cut contractors' cost. Depending on a contractor's experience level and the local recycling infrastructure, diverting waste from landfills can offer significant cost savings. For example, at Toronto's Pearson International Airport, recycling was to save the Terminal 1 replacement project an

estimated \$664,000. All concrete, asphalt, and metal products from the demolition of the 40-year-old, 156,077-m² terminal were recycled. The materials were being used as backfill for a 900-foot terminal pier and as a sub-base for a new apron, saving substantial trucking costs (Griffin, 2005). In another example, Xerox Corporation saves hundreds of millions of dollars each year through its remanufacturing and recycling programs, where 90% of old machine parts are refurbished and reused in new machines (The SIGMA Project, 2001). Therefore, it is in a builder's interest financially to embrace sustainability (Griffin, 2005). The rise in energy costs, shortage of building materials, will further make the Green Building more preferable to conventional buildings (Lee and Yik, 2004).

Increased restrictive regulations and competitive pressures, as well as growing demand from the public, place an increasing responsibility on AEC firms to implement Green Building projects. Besides the external forces, Green Building can also bring about benefits such as financial gains, enhanced corporate reputation, improved government relations, increased technology and innovation skills, and employee loyalty. Therefore, more and more AEC firms have embraced sustainability in their projects or are starting to do so (USGBC, 2003).

2.3 Critical Success Factors (CSFs)

The concept of "Critical Success Factors" (CSFs) was developed by Rockart (1982) and the Sloan School of Management (Jefferies, 2002) with the phrase first used in the context of information systems and project management. Rockart (1982) defined CSFs as: those few key areas of activity in which favourable results are absolutely necessary for a particular manager to reach his or her own goals...those limited number of areas where "things must go right". In a similar fashion, Rowlinson (1999) stated that CSFs are those fundamental issues inherent in the project, which must be maintained in order for team working to take place in an efficient and effective manner. The methodology of CSFs is particularly important with a large complex program and a large multilevel, geographically dispersed program team, since the

identification of CSFs can reveal the reasons for project success. There have been widespread theoretical and empirical studies completed on success factors of a project.

2.3.1. Literature Review of Success Factors on Construction Projects

Achieving success in a construction project is an important goal of project participants, while success means different things to different people (Lam *et al.*, 2008). Most of the past work seemed to use their own performance criteria for measuring success and the various factors contribute differently to different project objectives (Jaselskis and Ashley, 1991).

2.3.1.1. Success Factors for Schedule, Cost and Quality

Traditionally project performance is evaluated using schedule, cost, and quality performances, also known as the “iron triangle” (Jha and Iyer, 2007). The CSFs to implement projects for better schedule, cost and quality performance have been widely explored. Some of typical examples are listed as follows.

Chu and Shen (2002) examined how effective planning and control contribute to time performance. This study concluded that the abilities to understand the project’s complexity and to prepare flexible plans for solving unforeseen problems are essential factors to good time performance. Dov (2006) also identified five key determinants for construction schedule performance using neural network approach. The five key determinants include (in descending order of significance): “amount of time project managers devote to the project”, “frequency of meetings project managers hold with other project personnel”, “monetary incentive to designer”, “implementation of constructability program” and “project manager experience with projects of similar size and duration”. Iyer and Jha (2006) identified seven factors having significant influence on the schedule outcome. Among them, three factors: “commitment of the project participants”, “owner’s competence” and “conflict among project participants” have been found to possess the capability to enhance performance level while the

remaining four factors: “coordination among project participants”, “project manager’s ignorance and lack of knowledge”, “hostile socioeconomic environment” as well as “indecisiveness of project participants” tend to retain the schedule performance at its existing level. A review of literatures in this area suggests that the construction duration of a project is affected by a vast number of factors to varying extents. Chan (1998) proposed that these time-influencing factors in Hong Kong can be classified into four major categories: project-scope, project complexity, project environment and management-related attributes. Figure 2.1 has been developed to show the four categories and their principal associated factors that could influence construction project durations

Figure 2.1 Summary of Principal Factors Affecting Construction Duration of Projects (Chan, 1998)

For better controlling cost within an acceptable level, a large number of studies have been completed for identifying CSFs in this area. Ashley (1987) concluded that construction project success is repeatable and some success attributes identified for

better budget performance include: “planning effort in construction and design”, “project team motivation”, “project manager goal commitment”, “project manager technical capabilities”, “control systems”, “scope and work definition”, “clarity of project mission”, “top management support”, “project scheduling”, “client consultation” and “personnel selection and training”. Jaselskis and Ashley (1991) identified determinants for budget performance using logistic regression. They found that the most important variable is “implementation of constructability program”. Sanvido (1992) examined the contributions of different factors to project success and found “project team experience”, “contracts”, “resources and information available” as important factors. Besides, through neural networks as the analyzing method, Chua (1997a) identified eight factors which are most important for budget performance. These eight factors include (1) number of organizational levels from the project manager to the craft workers, (2) amount of detailed design completed at the start of construction, (3) number of control meetings during the construction phase, (4) number of budget updates, (5) implementation of a constructability programs, (6) team turnover, (7) amount of money expended on controlling the project and (8) the project manager’s technical experience. Akintoye (2003) examined factors that influence a contractor’s estimate of a project cost. Of the 24 factors, the researcher identified seven main factors using the factor analysis approach: “project complexity”, “technological requirements”, “information”, “team requirement”, “contract requirement” and “duration and market requirement”. CSFs affecting cost performance of Indian construction projects were obtained by Iyer and Jha (2005): “project manager’s competence”, “top management support”, “project manager’s coordinating and leadership skill”, “monitoring and feedback by the participants”, “coordination among project participants”, “owners’ competence” and “favorable climatic condition”. Further analysis indicated “coordination among project participants” as the most significant of all the factors having maximum positive influence on cost performance.

The quality of a construction project is also an important concern in any construction

project. Ling (2005) explored the CSFs and concluded that four factors affect quality scores of Design-Build (DB) projects significantly in Singapore. They are “DB contractors are allowed to propose changes to the contract”, “designer should be selected and engaged by owner”, “owner-appointed architects should prepare the scheme design” and “more design is completed before the budget is fixed”. Based on analysis of 54 cases in Hong Kong, a predictive model for quality performance was developed by Chan (2006). It concluded that the construction quality can be improved by: “appointing a project manager with extensive experience in running public housing projects”, “fostering a proactive quality culture”, “increasing usage of direct skilled labor”, “adopting a comprehensive inspection system on subcontractors’ work”, “increasing competency of site labor” and “the client’s emphasis on quality, safety and environment”. The CSFs for improving construction quality performance can be classified into seven main groups based on literature review as shown in Figure 2.2, namely: (1) client variables; (2) project nature variables; (3) project team leader variables; (4) project procedures variables; (5) quality training variables; (6) project management variables; and (7) quality culture variables.

Figure 2.2 Factors Affecting Quality Performance (Chan *et al.*, 2006)

Besides, there are also many studies conducted to determine the relative importance of success related factors according to the project objectives of budget, schedule, and quality. Chua *et al.* (1997b) identified eight key management factors that affect budget performance. These factors include “organizational levels between project manager and craftsmen”, “project manager experience”, “level of design completion at the start of the project”, “constructability program”, “project team workmanship rate”, “frequency of control meetings”, “frequency of budget updates” and “control system budget”. Using the same set of data, five key factors affecting schedule performance: “frequency of meetings”, “amount of time that project managers devote to the project”, “project manager’s experience”, “monetary incentives to designers” and “implementation of constructability program”, were found (Kog, 1999). Dissanayaka and Kumarawamy (1999a and 1999b) have also done research on identifying the critical reasons relating to time and cost performance on Hong Kong building projects. The results suggested that procurement sub-systems variables are less significant than the non-procurement related variables in predicting time and cost performance levels on Hong Kong building projects. The procurement sub-systems include “work packaging”, “functional grouping”, “payment modality”, “selection methodologies” and “standard sets of conditions of contracts”. The non-procurement variables include “project characteristics”, “procurement system”, “project team performance”, “client/client characteristics”, “contractor characteristics”, “design team characteristics and external conditions”. Chua *et al.* (1999) studied the effect of 67 success factors on the cost, time, and quality performance of a construction project. Variables were regrouped into four groups as a hierarchical model for project success as shown in Figure 2.3: project characteristics, contractual arrangements, project participants and interactive process. The result indicate that there were different sets of success factors for different project objectives.

Figure 2.3 A Hierarchical Model for Construction Project Success (Chua *et al.*, 1999)

2.3.1.2. Success Factors for Safety

In addition to the iron triangle, safety improvement can also be viewed as an important criterion for successful building performance and a number of researchers have proposed different sets of success factors for improving safety performance. Hinze and Raboud (1988) identified appropriate means of achieving or maintaining acceptable safety performance on large projects, which include: “employing a full-time company safety officer”, “strong top-management support for safety”, “conducting safety meeting for supervisors”, “monitoring supervisor safety performance”, “conducting specific jobsite safety tours”, “discussing safety issues in regularly held coordination meetings”, “employing sophisticated scheduling techniques” and “participation of the owner or owner’s representative in coordination meetings”. This research also concluded “job pressures” (particularly those imposed by budgetary constraints) can adversely affect safety performance. Liska (1993) identified zero accident techniques: “safety pre-project/pre-task planning (including safety goals, safety person/personnel, hiring employees, safety policies and procedures, fire protection program, accountability/responsibility, and safety budget concerns)”, “safety training and orientation required”, “safety incentive provided”, “alcohol- and substance-abuse program in place”, “accident and near-miss investigation conducted”, “record keeping and follow-up undertaken”, “safety meeting held and personal protective equipment employed”. Jaselskis (1996) provided quantitative strategies for achieving better construction safety performance at the

company and project level. The significant company-related factors are “upper management support”, “time devoted to safety issues for the company safety coordinator”, “number of informal safety inspections made by the company safety coordinator”, “meetings with the field safety representatives and craft workers”, “length and detail of the company safety program”, “safety training for new foremen and safety coordinators”, “specialty contractor safety management” and “company safety expenditures”. At the project level, several factors are important for achieving better safety performance: “increased project manager experience level”, “more supportive upper management attitude towards safety”, “reduced project team turnover”, “increased time devoted to safety for the project safety representative”, “more formal meetings with supervisors and specialty contractors”, “more informal safety meetings with supervisors”, “a greater number of informal site safety inspections”, “reduced craft worker penalties”, as well as “increased budget allocation to safety awards”.

2.3.1.3. Success Factors for Productivity

Construction productivity is a comparison between input and output, and is an increasingly important issue (Allmon *et al.*, 2000). The CSFs for improving productivity performance attracted more attentions in recent years. Allmon (2000) revealed four primary ways of increasing productivity through management, namely (1) planning; (2) resource supply and control; (3) supply of information and feedback; and (4) selection of the right people to control certain factors. Lam and Tang (2003) reported that “employees’ work environment”, “the ability to perform their designated role and motivation” are the main factors influencing their performance in an organization. Doloi (2008) suggested “increased pre-planning and programming” as the most critical factor to improve labor productivity on construction projects. “Construction pre-planning and programming” encapsulates the elements of “planning human and capital resources for a project through the construction phase”, “work scheduling”, “activity programming”, “site coordination planning” and “financial cash flow planning”. All these elements must be the initial focus of

construction organizations if they tend to improve upon current levels of labor productivity. Furthermore, “provision for incentives” has been suggested as the second most critical factor for improving labor productivity. Of the incentives investigated, the leading factor is “productivity bonuses”, with “financial incentives” being also an important incentive to increase productivity.

2.3.1.4. Success Factors for Certain Procurement Contracts

There has also been research which has identified the success factors that influence the performance of certain procurement strategies. Tiong (1992) did the first research in this area. They identified the CSFs in winning Build-Operate-Transfer (BOT) contracts. These factors are: “entrepreneurship”, “picking the right project”, “a strong team of stakeholders”, “an imaginative technical solution”, “a competitive financial proposal” and “the inclusion of special features in the bid”. Morledge and Owen (1998) and Cheng (2000) identified the CSFs for Project Finance Initiative (PFI) contracts and partnering projects respectively. Chan (2001) identified a set of project success factors for Design-Build (DB) projects and examined the relative importance of these factors. In this study, the success of the projects is measured by the ability to complete on time and within budget. The project success factors highlighted in this study include: “team commitment”, “contractor’s competences”, “risk and liability assessment”, “client’s competencies”, “end users’ needs” and “constraints imposed by end users”. In Lam’s (2005) research work, the various CSFs for DB projects identified from both researchers and practitioners in the industry were grouped into six categories, namely “project characteristics”, “project procedures”, “project management strategies”, “project-related participants”, “project work atmosphere” and “project environment” as shown in Figure 2.4.

Figure 2.4 A Conceptual Framework of CSFs for DB Projects (Lam, 2005)

2.3.1.5. Success Factors for Different Types of Projects

Many researchers followed this line of investigation to identify specific CSFs for different types of projects. Lester (1998) found a set of CSFs for new product development projects. These factors include “senior management commitment”, “organizational structure” and “risk management”. The Standish Group (Johnson *et al.*, 2001) found “management support”, “customer involvement” and “project planning” are CSFs for software projects. Dov (2006) identified four CSFs by comparing neural network and regression analysis for defense projects: “essential and urgent operational need”, “cohesion of the development team”, “existence of learning mechanisms in the development team”, as well as “definition of operational and technical requirements”.

2.3.1.6. Success Factors for Construction Process

A great deal of research, which focused on CSFs for better performance of specific areas of construction projects or the success of some specific type of projects, have been discussed above. Apart from that, there have been many studies on CSFs for the efficiency of the construction process, which is also regarded in literature as an important criterion for successful implementation of projects.

Arditi and Gunaydin (1998) studied the factors affecting project process quality with a questionnaire administered to persons responsible for companies' quality operations. According to this research work, the general means to improve process quality were "management commitment and leadership", "training", "teamwork", "use of statistical methods", "supplier involvement" and "customer service". Among them, "project managers" was found have a strong impact on process quality, especially on the scale of the whole company's training, teamwork, and cooperation networks. However, "statistical methods" was applied less successfully at the construction project level. A list of factors critical to the construction process has been also derived by Poon (2001). These factors include "clarity/definition of project objective", "scope of project", "project manager", "project team", "planning", "control", "appropriate size of work package", "communication and information management", "top management support", "environment", "health" and "safety".

2.3.2. Literature Review of Success Factors on Generic Projects

Exploring success factors for generic projects has also been a popular topic. Much of the research effort has been aimed at identifying the success factors on generic projects. Hayfield (1985) was the first person who identified the success factors on generic projects. He established two sets of factors that determine the successful outcome of a project: macro and micro factors. The micro factors include "realistic and thorough definition of the project", "efficient manner of project execution", "comprehension of project environment" and "selection of organizations for realizing

the project”. On the other hand, the macro factors include “formulation of sound project policies”, “clear and simple project organization”, “selection of key personnel”, “efficient and dynamic management controls” and “reliable management information systems”. One of the first efforts to classify success factors was also carried out by Schultz, Slevin and Pinto (1987). They classified factors as strategic or tactical. These two groups of factors affect project performance at different phases of implementation. The strategic factors include items such as “project mission”, “top management support” and “project scheduling” whereas the tactical group consists of “client consultation”, “personnel selection” and “training”. In a similar study conducted by Pinto and Prescott (1988), the relative importance of each group (tactical versus strategic) over the project life cycle was analyzed. It was found that the relative importance of success factors varies at different stages of the project’s life cycle, depending on the measurement of success used. In their follow-up work, Pinto and Slevin (1989) identified success factors and their relative importance for each stage of a Research and Development (R&D) project life cycle. Belassi and Tukel (1996) categorized success factors into four main groups. These are factors related to project managers, the project itself as well as factors associated with the organization and its external environment, as summarized in Figure 2.5.

Figure 2.5 Framework for Success Factors of Project (Belassi and Tukel, 1996)

Based on reviewing the previous works on project success, Chan (2004) classified success factors into five major groups: “project-related factors”, “project procedures”, “project management actions”, “human-related factors” and “external environment”, as shown in Figure 2.6.

**Figure 2.6 New Conceptual Framework for Factors Affecting Project Success
(Chan *et al.*, 2004)**

There were also many studies conducted on other specific aspects of project performance, as long as they are viewed as critical criteria for successful implementation of a project, such as project partnering (Larson, 1995) and contract disputes (Diekmann and Girard, 1995). Despite most of past studies' emphasis on only a limited facet of project success or some specific types of projects, they have undoubtedly contributed to the overall Critical Success Factors (CSFs) model and have enriched this body of knowledge.

2.4 The Development of Green Building in Singapore

Singapore is an equatorial country that lies on 11200 N latitude and 1041 E longitude. The land area of Singapore is approximately 659.9 km², and its population is 3.89 million. It possesses a climate with relatively high temperatures (average temperature of 24.7~31.3°C) all year round, high humidity (daily average humidity at 84.4%) and abundant rainfall throughout the year (annual average rainfall of 2134 mm)

(Department of Statistics, 2000). Living in a small and densely populated country with limited natural resources such as land, water and energy, the path towards sustainability is the only hope to sustain its growing population, social and economic developments (Yeo, 2004).

2.4.1. The Environmental Impacts of Building Industry in Singapore

In Singapore, the environmental pollution caused by building industry is a serious problem. For example, rising levels of waste generation is a critical problem for Singapore (Leong and Quah, 1995). C&D wastes contribute 9% of the total amount of waste generated in Singapore annually (Low, 1996), which are mainly caused by the higher rate of wastages for local contractors (between 4 and 12%). This is more than that of their counterparts, the Japanese contractors, who maintain their wastage level within 2% (Yeo, 2004). Such wastes are attributed to the employment of unskilled workers and poor site management in delivery, storage, handling, and fixing of the materials (Yeo, 2004). Furthermore, electricity is the most commonly used energy source and accounts for the majority of energy use in buildings in Singapore. More recent data quoted by Lee and Rajagopalan (2008) showed the use of electricity in buildings constitutes around 16% of Singapore's energy demand and that was 5307 GWh or about S\$1 billion. Since the energy and electrical consumption is relatively high, improving energy efficiency of building industry is a key strategy for Singapore to remain competitive globally (Sim, 2003). Besides construction waste and energy consumption, Lim (1993) found that construction site workers and residents of nearby homes experienced varying levels of annoyance with noise (from machinery such as piling machines, concrete pumps and heavy vehicles), water (from discharge of silt, cement slurry, oil-based products, and wastes) and air (dust and smoke) pollution.

Since buildings contribute a large amount of the environmental problems, Singapore is looking towards Green Building in addressing the environmental problems at hand and more research work should be conducted for improving the environmental performance of building projects. This is especially in consideration of the Kyoto

Protocol (an amendment to the United Nations Framework Convention on Climate Change (UNCCC)) that Singapore recently signed in April 2006 where it committed to reduce the amount of greenhouse gases emission, so as to address the global issue of global warming (Chua, 2007). In the next section, the Singapore's efforts to attain sustainable development in building industry are discussed.

2.4.2. The Efforts of Singapore towards Green Building

Sustainable development is always a major concern of Singapore's government. Since the serious environmental impacts caused by building industry has been realized in recent years, the government authority in Singapore has taken steps to reduce their impacts through stringent regulations, financial incentives as well as education and training.

2.4.2.1. Mandatory Regulations

In order to encourage the building industry to progress towards environmental sustainability, some strict regulations are enforced, which lay down the mandatory level of performance. Singapore's Green Plan was first introduced in 1992. The latest edition, the Singapore Green Plan 2012 (Ministry of the Environment and Water Resources, 2006), covers the following focus areas: (i) air and climate change, (ii) water, (iii) waste management, (iv) nature, (v) public health, and (vi) international environmental relations (Ofori, 2007). Two aspects of Green Plan 2012, which are particularly relevant to housing are: "clean land" and "clean air". To ensure clean land, it is necessary to manage waste effectively, especially for Construction and Demolition (C&D) wastes. For clean air pertinent to housing, the concentrations of major air pollutants (dust generated by building activities) should be below the levels set by the World Health Organization. Besides, the energy consumption of buildings in Singapore should be reduced by using energy sources that emit less pollutants, such as natural gas (Ofori, 2007).

To better management of industrial waste, the Environmental Public Health

(Amendment) Act 1999 established stiffer penalties for illegal dumping. Offenders can be fined up to S\$50,000 on conviction (for repeat offenders, up to S\$100,000), and imprisoned for up to 12 months (The Straits Times, 1999). Noise pollution is also one of the environmental issues caused by building activities and has been tightly controlled by the Ministry of Environment (ENV), under the Environmental Public Health (Control of Noise from Construction Sites) Regulation 1990. Under the regulations, a construction site may be required to measure and the site's noise level and to submit records of the readings (Teo, 1999).

To ensure that construction sites in Singapore are free from environmental hazards which would affect the workers and nearby residents, implementation of the Environmental Control Officer (ECO) Scheme was brought up in the Environmental Public Health (Employment of Environmental Control Officers) Order 1999. This scheme requires the construction site to employ a competent person to act as an ECO on a full-time or part-time basis (Ofori, 2007). The ECO is responsible for the identification of potential or actual environmental health problems on the site. He has to offer advices and recommend measures to the contractor on how best to solve these problems. Educating workers on the possible environmental health hazards is another important aspect of his responsibility (Ng, 2004).

The most important effort by Singapore towards Green Building is the launch of Green Mark Scheme for buildings by the Building and Construction Authority (BCA) in January 2005. This scheme can be used to determine the extent to which the building meets the desirable environmental criteria. Green Mark is applicable to both new and existing buildings. New buildings are assessed under: (i) Energy Efficiency, (ii) Water Efficiency, (iii) Site and Project Development and Management, (iv) Indoor Environmental Quality and Environmental Protection, and (v) Innovation. On existing buildings, "Site and Project Development and Management" is replaced with "Building Management and Operations". In order to be certified, buildings have to score at least 50% of the points in each category other than the innovation category;

they should also chalk up a minimum overall total number of points. Depending on the total points awarded, a building may then be awarded: Platinum, Gold^{Plus}, Gold or Certified ratings. To ensure that buildings given the Green Mark are well maintained, they are assessed once every two years (BCA website). In order to be awarded by Green Mark, several characteristics of this scheme should be noted. Firstly, Green Mark plays strong emphasis on energy efficiency and renewable energy. Energy efficiency has the highest percentage (30%) of the points in Green Mark (Yang, 2006). Secondly, Green Mark encourages the incorporation of innovative design strategies, technologies and construction methods for building projects (Yang, 2006). The category of innovation takes up 15% of the total points. Thirdly, Green Mark places more emphasis on design stages. Yang (2006) concluded that the criteria related to architectural accounts for 40% of the total points. However, in comparison, the Green Building measures in construction and demolition stages have not been paid enough attention. Fourthly, Green Mark certified projects have perceived higher upfront cost. In general, a large investment is needed to achieve a higher rating. Chu (2008) found it typically takes about a maximum of eight years to recover the upfront cost through life cycle cost savings.

After the birth of the BCA Green Mark Scheme, the number of Green Mark certified projects had increased significantly from 17 projects in the first year (2005) to 96 in 2007 (Chu, 2008). Since April 15, 2008, all new buildings with a Gross Floor Area (GFA) of more than 200 m² are required by law to meet the minimum Green Mark certification standard, leaving building owners, developers and AEC firms no choice but to incorporate sustainable practices into their building projects. The master plan of BCA is to achieve “80% of all the buildings in Singapore certified by Green Mark by 2030.” It aims to promote a sustainable built environment by incorporating best practices in environmental design and construction (BCA website).

Studies show that the level of environmental awareness in Singapore’s construction industry is rising (Tan *et al.*, 1999; Ofori, 2000). However, since the present state of

the construction industry is already highly regulated, any more regulations may have a counter effect of stifling innovation (Teo, 1999). Therefore, some non-mandatory programs have been provided by government in Singapore to promote the development of Green Building and reduce the environmental impacts of building industry. Some main non-mandatory programs including leadership, financial incentives, as well as education and training are described as follows.

2.4.2.2. Non-mandatory Programs

(1) Leadership

The Singapore government believes that it should take the lead by requiring government-commissioned buildings to achieve higher Green Mark certification and set a trend for private building owners and developers to follow. As a result, the Singapore Government has launched a Green Building Master Plan: from April 2007, all new public-sector buildings will have to achieve the highest Platinum standard and all existing public buildings will be upgraded to meet the Gold^{Plus} standard at a cost of \$500 million by 2020 (BCA website). The Housing and Development Board (HDB), as the agency for managing public housing and the nation's largest housing supplier, has achieved ISO 14000 certification. This plays a key role in raising contractors' awareness on environmental issues by encouraging firms to utilize the ISO 14000. Besides, for HDB building projects, some Green Building measures should be incorporated, for instance, sunshades and overhangs have already been incorporated into building façade in newer flats. The big public sector (86% of the population lives in public houses) could contribute significantly to the environment if the use of Green Building materials and products from sustainable sources is adopted (Tan, 2006).

(2) Financial incentives

In order to encourage private owners and developers to attain higher Green Mark rating, Singapore government provides several incentive programs. BCA is handing out free Gross Floor Area (GFA) for new private buildings (a suggestion made by industry players during the report's feedback sessions): developers who build Green

Mark Gold^{Plus} buildings will get an extra 1% of GFA, capped at 2500 m²; while Platinum buildings will get an extra 2%, capped at 5000 m². Industry players such as City Developments' managing director Kwek Leng Joo have welcomed this policy. Mr. Kwek said that this will "help developers defray some investment in green technology and features". The Government has also set aside a \$600 million fund to green existing public and private buildings. Furthermore, BCA launched the BCA Green Mark Champion Award at the BCA Awards 2008. This new award recognizes developers/building owners with strong commitment towards corporate social responsibility and outstanding achievements in environmental sustainability. It is given to developers/building owners who achieve a substantial number of Green Mark buildings at Gold level and higher (BCA website).

(3) Education and training

Education and training are fundamental to create an awareness and knowledge of Green Building. A lack of them is a significant barrier in the implementation of Green Building practices (Yeo, 2004). Singapore government had recognized the importance of educating and training on construction professionals in reducing the environmental impacts caused by building industry and promoting Green Building movement. Several training programs have been provided. For example, the Certified Green Mark Manager (GMM) & Green Mark Professional (GMP) Program, a training and recognition scheme, was introduced by BCA to raise industry capability in the niche area of sustainable design and development. Designed as a voluntary career upgrading for building professionals, this scheme recognizes individuals with the relevant competencies in Green Building design and practices. Candidates seeking accreditation as Certified Green Mark Manager or Professionals with BCA, besides meeting other pre-requisites, would need to complete the certification course. Until 2009, five Certified Green Mark Professionals, 39 Certified Green Mark Managers have been recognized. BCA has also put in place, "Contractors' Registry System (CRS) Step-Up" program, which assists Small and Medium Enterprise (SMEs) to achieve ISO 14000 certification. This program provides a grant of up to 70% of

consultancy cost in Environmental Management System (EMS) (MND, 2002b). By the mid of 2002, 25 out of the 73 building and civil engineering contractors in the top A1 and A2 grades had gained accreditation. An additional 16 were preparing for it (Yeo, 2004). Furthermore, a searchable database “sustainable building information system (<http://www.sbis.info>)” has been created by BCA to provide non-commercial information about Green Building around the world. It can help the public to extend their knowledge. Initiative developers can also use the database to keep abreast of technologies the other developers employed (BCA website). In addition, The Singapore Institute of Architects (SIA) organizes seminars and talks on aspects of green design, and holds an ‘eco-design’ competition every year. Some Singapore architects have attained recognition as being committed to environmental design suitable for the tropics (Ofori and Kien, 2004). The National Environment Agency (NEA) has been working with BCA in organizing environmental seminars for construction practitioners to share best practices in environmental management (Yeo, 2004).

Since the government in Singapore is doing its part to enhance environmental awareness at all levels by providing education and training programs, financial incentives, demonstration projects on Green Buildings, and enacting stringent regulations as well as developing a building assessment system, great achievements have been made in the path of environmental friendly buildings.

2.5 Research Gaps for Further Investigation

The body of research relating to the implementation of Green Building has been increasing rapidly over the last few years. These studies mainly focus on the environmental impacts of building industry and how to reduce these impacts through technical solutions, the financial and social impacts, as well as the barriers for the integration of these technological solutions. Besides, in order to assess the environmental performance of these solutions and the entire building after completion, many assessment systems have been developed and more detailed performance

indicators have been provided. Architecture/Engineering/Construction (AEC) firms, who are the main players in the design and construction stages, play essential roles in improving environmental performance along the whole construction process (Wu, 2003). A survey conducted by Khoo (2002) also concluded that architects, contractors and engineers are regarded as the most important participants in influencing the practice of Green Building. At present, more and more legislative measures, designed to reduce environmental degradation, place an increasing reliability on AEC firms. AEC firms face major challenges now caused by increasingly restrictive laws and regulations to improve the environmental performance. In Singapore, Green Building has become a compulsory requirement, which leaves the AEC firms have no choice but to implement Green Building initiatives. Therefore, more research works should focus on the role of AEC firms in Green Building. In addition, research that focuses on Green Building from the AEC firms' perspective is limited and most AEC firms new to Green Building projects do not know where to begin in order to improve the environmental performance and get the building to be certified by the corresponding building authority. That is also echoed by Tan (2006), which concluded that "there are limited experienced contractors to deliver Green Building projects in Singapore. This in turn will hamper the progress of works, which will result in longer time spent and unnecessary costs incurred."

Furthermore, many technologies, products and Green Building measures have been well developed today (for example green roof, advanced simulation and analysis tools, and new and unfamiliar recycled materials) and some of them have been applied in the building industry during the design and construction stages. However, integrating these numerous Green Building measures into building design and construction is a complex process and they will not be effectively adopted without appropriate management enforcement. In addition, the current construction management approach does not align with the sustainability goal (Sharon, 2002). It can result in actions that encourage environmental destruction, poor quality control, and wasteful behavior (Imada, 2002). Therefore, in order to construct Green Building, there is a need for

changes in the way construction projects are managed. However, previous studies mainly focus on technical methods and engineering procedures, with fewer considerations given to the management process. Therefore, this research aims to bridge this gap by focusing more on management strategies, which would allow the matching of the activities of AEC firms to the implementation of Green Building. There is also a lack of methodology, which can assist the analysis on management approach for delivering the Green Building projects from the viewpoint of AEC firms. A large body of research suggests that many of the reasons behind project success can be found in the existence of Critical Success Factors (CSFs) (Pinto and Covin, 1989) and comprehensive analysis of CSFs can help AEC firms to maximize their contributions to Green Building projects effectively and efficiently. The CSFs approach has been established and popularized over the last 20 years and CSFs for the project success have been widely investigated. However, the majority of the studies mainly focus on the cost, quality and schedule of the projects as illustrated in the literature review, there is a noticeable shortage of research studies that focus on sustainability of buildings.

In summary, the research gaps to promote the development of Green Building from the perspective of AEC firms are as follows. Firstly, models which can guide AEC firms new to Green Building towards sustainability have not been provided. Secondly, CSFs of AEC firms to improve the environmental performance of building projects have not been investigated.

2.6 Chapter Summary

In this chapter, the main body of existing literature on Green Building and CSFs methodology is summarized. It also presented the current development practices of Green Building in Singapore and provided a context for the study. Based on reviewing the literature, the research gaps which need further investigation in this field are demonstrated.

Chapter 3 Research Methodology

3.1 Introduction

The research methodology applied in the study is presented in this chapter. The specific objective of this research is to explore the Critical Success Factors (CSFs) for Green Mark certified projects. The methodology chosen should fit the issues to be studied, rather than structuring the issues to fit a preferred method. Based on this consideration, literature review, questionnaire survey and interview can be used in this dissertation to collect data. Prior to conducting industry-wide questionnaire, pilot study is carried out to identify possible areas for improvement and the final contents of the questionnaire are then outlined. After that, the strategy for data distribution is described. Then, multiple regression analysis and factor analysis as the main data analyzing techniques are discussed. Finally, a series of case studies were conducted which can validate the questionnaire survey results. All these methods used in this study are shown in Figure 3.1.

3.2 Data Collection

Collecting data is essential for the identification and validation of Critical Success Factors (CSFs) for building projects. In this study, literature review, pilot study and questionnaire survey are used for data collection. The specific purpose and application of these methods are discussed in detail as follows.

Figure 3.1. Flowchart of Research Methodology in This Study

3.2.1. Literature Review

An extensive literature review forms the foundation of this research analysis. Sekaran (1992) defined a literature review as a preliminary gathering of data. In this study, the literature review can provide important information of construction practices on Green Building projects and help to identify relevant Critical Success Factors (CSFs) for developing questionnaires. The sources of literatures covered a wide range of journal papers, books, conference proceedings, dissertations and other publications related to the topics. There were mainly two parts for the application of literature review in this thesis. In the first part, the comprehensive reviews of the current development of Green Building and the methodology of CSFs, which were the focuses of recent research, were presented in Chapter 2. Based on the literature review, the research gaps were also identified. In addition, based on reviewing the literatures, the Generic Revolution Model for AEC firms for Green Buildings was constructed and the CSFs framework within the control of AEC firms was established. All these models, which can fulfill the research gap to improve decision-making in AEC firms

to maximize sustainability of building projects, were presented in Chapter 4. Literature review is one of the core components in the entire research methodology.

3.2.2. Pilot Study

Before the industry-wide survey, a pilot study was carried out. Walker (1997) concluded that “a pilot study has proved to be a useful tool in providing a focus mechanism to establish the research direction more clearly”. The pilot study can provide relevant information for the development of the questionnaire. In this study, face-to-face interviews were conducted with four industry professionals (Certified Green Mark Managers issued by BCA) who are familiar with Green Mark certified projects in Singapore. All the four professionals have more than ten years experience in building industry and have been involved in at least two Green Mark certified projects in Singapore. Besides the industry practitioners, the preliminary questionnaire was also sent to two professors and two researchers, who were very familiar with this research area. These pilot study participants were encouraged to comment on: whether the questionnaire asks appropriate and sufficient variables or does the questionnaire miss any other important variables. The main aim of interviews is to ensure that the information sought in the questionnaire is relevant to the current practice. They also provided valuable advice on the relevance, accuracy, phrasing, sequencing, layout of the questionnaire and time needed to complete the survey. Based on their feedback, the questionnaire was finalized and the formal survey was carried out in Singapore.

3.2.3. Survey Methodology

Although the basic theoretical models could be established by reviewing former researcher’s work, these models still need to be strengthened by some empirical studies and analysis. One can’t easily draw constructive conclusions in detail without practical data. Generally, surveys can be adopted to collect practical data. Therefore, in this study, the primary data collection method is a structured questionnaire.

3.2.3.1. Questionnaire Survey

A questionnaire is a pre-formulated written set of questions to which respondents record their answers, usually within rather closely designed alternatives (Sekaran, 2003). A large sample can be obtained through questionnaire survey at a relatively low cost. It is particularly useful when the sample data are spread widely around the country, and it is impossible to collect all the data by interview. In this study, a delicate questionnaire was designed and conducted to explore Critical Success Factors (CSFs) for AEC firms to improve the environmental performance of building projects so as to achieving Green Mark certification. The design of questionnaire followed the guidance provided by Dillman's (1978) Total Design Method. The Total Design Method intends to improve the usefulness, validity and cost-effectiveness of survey methods by providing instructions for cover, format, questions and page layout. The results of the survey will be analyzed through statistical methods.

3.2.3.2. Design of the Questionnaire

The questionnaire consists of 5 pages and is divided into three parts (Appendix A). The following section provides a detailed discussion of the questionnaire design.

(1) Part I - Background information about the respondents

Part I of the questionnaire requested respondents' background information, for the purpose of identifying whether the respondents are suitable targets. Obviously, the questionnaire targeted mainly professionals in AEC firms who have extensive experience in building industry and Green Mark certified projects in Singapore. Therefore, this part contained three questions, including the respondents' designation, year of experience in building industry (years) and the number of Green Mark certified projects they have been involved in.

(2) Part II - Background information about the respondents' firm

In part II, the respondents were first asked to provide background information of the firms they are affiliated, which included three questions: the organization's name,

total number of full-time employees in the company and whether their firms have been certified for environmental management systems (such as the ISO 14000 series). After that, they were asked to evaluate the performance of their firms in terms of eleven organizational factors, identified from the literature review, as show in Table 3.1.

Table 3.1 Critical Organizational Factors for Green Building

Codes	Organizational Factors	Definition
O1	Financial strength	Scale 1-5; 1=Poor; 5=Excellent
O2	Technical competency	Scale 1-5; 1=Poor; 5=Excellent
O3	Experience and knowledge in Green Building	Scale 1-5; 1=Poor; 5=Excellent
O4	Training and education	Scale 1-5; 1=Poor; 5=Excellent
O5	Qualified employees	Scale 1-5; 1=Poor; 5=Excellent
O6	Incentives and compensation policies and system	Scale 1-5; 1=Poor; 5=Excellent
O7	Company image	Scale 1-5; 1=Poor; 5=Excellent
O8	R&D capability	Scale 1-5; 1=Poor; 5=Excellent
O9	Innovation capability	Scale 1-5; 1=Poor; 5=Excellent
O10	Organizational structure - Formalization	Choose one or more items for which the firm has established formalized procedures, rules, or regulations, scale 0-10
	Organizational structure - Centralization	Choose one or more decision-making items which are controlled by the headquarter, scale 0-10
O11	Organizational culture	Choose one or more items which represent an influential theme in the company culture, scale 0-9

Most of the organizational factors were qualitative variables expressed on a five-point scale ranging from [1=Poor] to [5=Excellent], except organizational structure and organizational culture. According to the thesis of Kang (2006), organizational structure can be characterized by formalization and centralization. Formalization was defined as the degree to which rules, regulations, policies and procedures are explicitly specified and adhered to in an organization. The areas within which rules, regulations, policies and procedures are commonly found in: (1) environmental

management; (2) responsibility of the department; (3) quality management; (4) human resource management; (5) contract management; (6) financial management; (7) cost management; (8) project management; and (9) technology management. Therefore, the results are measured on a scale of 0-10. Centralization refers to the extent of participation by organizational members in decision-making. In a centralized organization, final choices are made almost exclusively at high levels and unquestioning acceptance of top management decisions is expected. Such organizations are characterized with minimum level of participation from lower level members of the organization. Therefore, in order to test whether an organization is centralized, some decision-making items are listed to see whether these items are actually controlled by the headquarters. These items include: (1) bidding decision; (2) selection of technological scheme; (3) material procurement; (4) project cost control; (5) setting of contractual terms; (6) capital budget control; (7) subcontractor selection; (8) environmental performance control; and (9) structure of project team. The results are similarly measured on a scale of 0-10. In order to investigate the organizational culture of the responding organization, the respondents were also asked to choose one or more items in terms of: (1) project environmental impacts and protection; (2) customer satisfaction; (3) project quality (4) innovation; (5) human development of capital; (6) organizational learning; (7) cooperation of employees; (8) reputation and brand name, to check whether the target company has a broad culture or only focuses on one or two aspects. All these values/norms can be found in a typical firm and may affect the environmental performance of building projects. The results are measured on a scale of 0-9. Based on the performance measurements, the more important organizational factors to improve the environmental performance of building projects can be identified.

Finally, the respondents were asked to rate the performance of their firms' external relationships with other stakeholders. The external stakeholders that should participate in the design and construction stages of Green Building were listed in Table 3.2. Extent of quality of relationship for each stakeholder was scored on a five-point

interval measure: [1=Poor] to [5=Excellent]. Based on these measurements, the stakeholders, who are more important for Green Mark certified projects, will be extracted by statistic analysis in Chapter 5.

Table 3.2 Critical Firms' External Relationships for Green Building

Codes	Firms' External Relationships	Definition
E1	Relationship with qualified/certified materials and products suppliers	Scale 1-5; 1=Poor; 5=Excellent
E2	Relationship with advanced equipment suppliers	Scale 1-5; 1=Poor; 5=Excellent
E3	Relationship with qualified/certified sub-contractors	Scale 1-5; 1=Poor; 5=Excellent
E4	Relationship with good green consultants	Scale 1-5; 1=Poor; 5=Excellent
E5	Relationship with qualified/certified planners	Scale 1-5; 1=Poor; 5=Excellent
E6	Relationship with clients	Scale 1-5; 1=Poor; 5=Excellent
E7	Relationship with qualified/certified demolition contractors	Scale 1-5; 1=Poor; 5=Excellent
E8	Relationship with Finance institutions	Scale 1-5; 1=Poor; 5=Excellent
E9	Relationship with government	Scale 1-5; 1=Poor; 5=Excellent

(3) Part III - Green Building projects information

Part III was to rate one Green Mark building project the respondents have been involved in. This part was further divided into three sub-sections. The first sub-section gathered background information about this project. The questions include: name of the project, nature of the project, building type, Green Mark level certified of this project, and type of client for this project. The second sub-section sought information about the project procedures: bidding procedure, procurement method and contract type of the project. The third sub-section of the questionnaire asked the respondents to indicate the project management performance related to the identified 19 factors, which have a potential effect to improve the environmental performance of building projects. Most of the factors were qualitative variables expressed on the Likert scale of 1 (Poor) to 5 (Excellent), as shown in Table 3.3.

Table 3.3 Critical Project Management Factors for Green Mark Certified Projects

Codes	Critical project management factors	Definition
P1	Support from senior management	Scale 1-5; 1=Poor; 5=Excellent
P2	Skilled designers	Scale 1-5; 1=Poor; 5=Excellent
P3	Skilled project managers	Scale 1-5; 1=Poor; 5=Excellent
P4	Trouble-shooting	Scale 1-5; 1=Poor; 5=Excellent
P5	Project team motivation	Scale 1-5; 1=Poor; 5=Excellent
P6	Commitment of all project participants	Scale 1-5; 1=Poor; 5=Excellent
P7	Cooperation between architects and engineers	Scale 1-5; 1=Poor; 5=Excellent
P8	Designers involved in construction stages	Scale 1-5; 1=Poor; 5=Excellent
P9	Contractors involved in design stages	Scale 1-5; 1=Poor; 5=Excellent
P10	Strong/detailed plan effort in design and construction	Scale 1-5; 1=Poor; 5=Excellent
P11	Adequate communication channels	Scale 1-5; 1=Poor; 5=Excellent
P12	Effective environmental compliance and auditing programs	Scale 1-5; 1=Poor; 5=Excellent
P13	Effective feedback	Scale 1-5; 1=Poor; 5=Excellent
P14	Advanced machinery and equipments	Scale 1-5; 1=Poor; 5=Excellent
P15	Effective and efficient software development and application	Scale 1-5; 1=Poor; 5=Excellent
P16	Innovative management approaches	Scale 1-5; 1=Poor; 5=Excellent
P17	Innovative technological approaches	Scale 1-5; 1=Poor; 5=Excellent
P18	Innovative financing methods	Scale 1-5; 1=Poor; 5=Excellent
P19	Adequate financial budget	Scale 1-5; 1=Poor; 5=Excellent

Eventually, open-ended questions were provided for respondents to list any other important management factors of AEC firms for the Green Mark projects. They can also list other comments for improvement, if any.

3.2.4. Interview

Interview is a method, which involves collecting data by asking questions to selected participants face-to-face to find out what they do, think and feel (Thomas, 2004). Personal interview was conducted in this research into two stages: prior to the questionnaire design and after summarizing the survey results. In the first stage, the purposes of interview are to validate CSFs and to ensure the questions are correctly organized. In the second stage, the aims of interview are to validate the survey results and to illustrate why these factors are important and how to improve the performance of projects and organizations in these factors.

3.3 Data Distribution

The target population of the questionnaire survey is all the professionals and decision-makers in the building industry, including project managers, architects, engineers and consultants, who have experience in building industry in Singapore and have been involved in Green Mark certified projects. Since it is difficult to find out the exact population, the strategy used in this study was to identify the AEC firms which have conducted Green Mark certified projects based on the information provided on the website of the Building and Construction Authority of Singapore (BCA). Contacts were then established with the professionals and decision-makers of these AEC firms who were responsible for the Green Mark certified projects. As an incentive to encourage participation, it was conveyed in the survey questionnaire that the findings can be shared with the respondents. At Last, a total of 89 questionnaires were distributed.

3.4 Data Analysis Methods

Data analysis is a process through which meaning is given to the data. More specifically, data analysis consists of examining, categorizing, tabulating, or otherwise recombining the evidence to address the initial propositions of the study (Yin, 1994). The data analysis methods in this research involved factor analysis and multiple

regression analysis. The data was analyzed through Statistical Package for Social Sciences (SPSS) software package in this study.

3.4.1. Multiple Regression Analysis

Regression analysis is by far the most widely used and versatile dependence technique, applicable in every facet of business decision-making, ranging from the most general problems to the most specific (Hair *et al.*, 1995). This statistical technique can be used to explore the importance level of several independent (predictor) variables contributing to a single dependent (criterion) variable by studying the relations among them. The specific objective of this research is to examine the relative significance of project management factors, organizational factors and firms' external relationships adopted by AEC firms in Singapore for improving the environmental performance of building projects. This technique can best achieve this objective and is therefore chosen to be the principal instrument for this study. The multiple linear regression equation of dependent variable (y) upon the independent variables ($x_1, \dots, x_p$) is expressed in Equation 3.1

$$y = \beta_0 + \beta_1(x_1) + \beta_2(x_2) + \dots + \beta_p(x_p) + e \quad \text{Equation 3.1}$$

Where y represents the dependent variable, $x_1 \dots x_p$ are the independent variables; the parameters $\beta_1, \beta_2, \dots, \beta_p$ are the partial regression coefficients; the intercept β_0 is the regression constant; and e is the error term.

Sequential search methods have in common the general approach estimating the regression equation with a set of variables and then selectively adding or deleting variables until some overall criterion measure is achieved (Hair *et al.*, 1995). There are different sequential search approaches, namely stepwise estimation, forward addition and backward elimination. Stepwise estimation is the most popular sequential approach to selecting variables (Hair *et al.*, 1995; Norusis, 2000). It is combination of forward selection and backward elimination. At each step, the independent variable not in the equation which has the smallest probability of F was entered, if that probability was sufficiently small. Variables already in the regression

equation were removed if their probability of F became sufficiently large. The method terminated when no more variables were eligible for inclusion or removal (Jin and Ling, 2006). In this study, the stepwise method was chosen to select variables for the multiple regression analysis.

3.4.2. Factor Analysis

In this study, underlying relationships may exist among the large number of project management factors. Since the presence of large inter-correlations between the independent variables could affect the results of a multiple regression analysis, prior to conducting the multiple regression analysis, factor analysis is performed to group these interrelated variables into a smaller number of underlying factors (Chan, 1996). According to Hair (1995), factor analysis is useful in analyzing the interrelationship among a large number of variables and in explaining these variables in terms of their common underlying dimensions or factors. Many researchers from other areas including politics, sociology, economics, human-machine systems, accident research, taxonomy, biology, medicine, geology, and construction management have also applied this technique (Chan, 2001; Child, 1990; Iyer, 1996; Trost, 2003). Therefore, in this study, factor analysis was employed to explore the underlying constructs of the identified project management factors.

There are two important steps for factor analysis: factor extraction followed by factor rotation (Norusis, 1993). The goal of factor extraction is to determine the factors through principal components analysis, whereas factor rotation is to make the factors more interpretable.

Principle components analysis is a common method in factor extraction. It involves the generation of linear combinations of variables in the way of factor analysis so that they account for as much of the variance present in the collected data as possible. The eigenvector with the highest eigenvalue is the principal component of the data set (Sharma, 1996). The eigenvalue is a mathematical property of a matrix used both as a

criterion for determining the number of factors to extract and as a measure of variance accounted for by a given dimension (Kim and Mueller, 1994). This study adopts the criteria “eigenvalue greater than one rule” for component extraction. That states that only those variables whose eigenvalues are greater than one are retained. (Lam *et al.*, 2008).

Since the factors extracted using principle component analysis are orthogonal and contain a large number of overlapping attributes, it is not amenable to understand. So oblique rotation using varimax rotation is employed (Iyer and Jha, 2005). Varimax is the most popular rotation method used in factor analysis. It is an orthogonal rotation method that minimizes the number of variables that have high loadings on each factor (Chung, 2007). The factor loading is the correlation coefficient between an original variable and an extracted factor (Teo *et al.*, 2005). The larger the factor loading, the greater the factor contributes to the component. The goal of rotation is to achieve simple factor structure (i.e. high factor loadings on one factor and low loadings on all others), which simplifies the interpretation of the factors.

3.4.3. Case study

In this research study, a qualitative case study approach was further conducted. The main objective of this research was to validate the findings from the quantitative phase. A secondary objective was to obtain a more in-depth understanding about potential root reasons for these factors affecting the achievement of Green Mark in Singapore, which the quantitative survey could not properly address.

Case study research is a strategy often used in project management. Many researchers have adopted the case study approach in their research (Rowlinson, 2001; Awakul and Ogunlana, 2002). In general, case studies are the preferred strategy when dealing with “how” and “why” questions, when the investigator has little control over events, and when the focus is on a contemporary phenomenon within some real-life context (Yin, 1994). The case study method of research is appropriate for the present study because

the research questions ask “how”, and the researcher has no control over the behavioral events that occur in the chosen setting, and the problem under study is a contemporary phenomenon.

Data gathered are mainly drawn from two sources: publicly available materials (e.g. through the internet, newspaper, articles, books and project documents) and personal interview. Publicly available materials about case project and companies form the preliminary source for gathering data. Nonetheless, the research cannot solely rely on this type of data, because most of the publicly available materials are very general, and may not provide sufficient information. Thus, the personal interview constitutes a complementary source for gathering data. In order to get these unpublished information, face-to-face conversation with professionals in AEC firms who have extensive experience in Green Mark certified projects in Singapore were conducted. These interviews were supported by semi-structured interview outline that contained mostly open ended questions, which allowed interviewees greater freedom to share their experience and knowledge. The interviewees were free to expand on their answers or discuss other related matters. Generally, the interview outline was sent to the interviewees one week before the interview, which may help interviewees prepare answers for the questions. The approximate length of each interview was one hour. Follow-up interviews were completed by e-mail or telephone. All the interviews were recorded on paper. Case studies of each project were written primarily using this data.

Results of the case studies are presented in two parts: within-case and cross-case results. Within-case results focused on the findings derived from each case whereas the cross-case results aggregated these findings and formed the basis for comparison. Cross case analysis was generally conducted to identify patterns and themes (Miles and Huberman, 1994). When a pattern from one case is corroborated by the evidence of the same pattern from another case, the findings are stronger and more grounded (Eisenhardt, 1989). This technique is usually used to enhance the generalizability of the results, deepen our understanding and improve the explanations. The detail

description of the case study results is presented in Chapter 6.

3.5 Chapter Summary

The data collection methods adopted in this study were firstly presented. Literature review can explore the potential CSFs for improving environmental performance of building project. Questionnaire survey was then used as the principal empirical quantitative data collection method to identify the important factors for Green Mark certified projects. The design of the questionnaire was described in details followed by pilot study. Interview was mainly used to collect qualitative data from the industry. After that, the strategy for data distribution was also described, since the random sampling usually gets a very low response rate. The techniques for data analysis in this study, including multiple linear regression and factor analysis, were also presented. Finally, case study approach used to validate and illustrate the findings from the quantitative phase was described.

Chapter 4 Generic Revolution Model and Critical Success Factors (CSFs) Framework for AEC Firms towards Green Building Projects

4.1 Introduction

In this chapter, the value chain and system frameworks for Green Building, an extended application of Porter's value chain and system models, are introduced. Based on deep analysis of the value chain and system frameworks for Green Building, a Generic Revolution Model for AEC firms towards Green Building is created. Besides, the generic Critical Success Factors (CSFs) for Green Building projects, including project management factors, organizational factors and external relationships within the control of AEC firms, are proposed.

4.2 Procedures of Exploring Revolution Model and CSFs Framework of AEC Firms towards Green Building

Based on deep understanding of value chain and value system frameworks for Green Building, the Generic Revolution Model and Critical Success Factors (CSFs) framework for the AEC firms are established. The Generic Revolution Model includes Green Building performance, Green Building measures, support activities. While the generic CSFs framework, which mainly focuses on support management activities within the control of AEC firms, include three classifications of activities: project management activities, organizational activities and external relationships. In order to identify the critical activities in the generic models systematically and comprehensively, several other domains of knowledge should be explored first. The proposed procedures and major components for the identification are shown in Figure 4.1; the principal relations among them are illustrated as well.

- Before identifying all the support project management activities and support organizational activities, it is necessary to examine Green Building measures and Green Building performance by summarizing Green Building rating systems. This examination could help understand the characteristics of Green Building projects. Then, the support project management activities and support organizational activities, which may have potential impacts and influence on Green Building performance or the application of Green Building measures, can be identified completely.
- The support management activities can be comprehensively explored by using the resource-based view (RBV) of the AEC firms and Cheah's conceptual model. The two domains of knowledge can provide insight to the fundamental components of an organization, which directly relates to the solution to this research problem.
- The support project management activities can be identified by summarizing the previous literature in this area. These identified activities are embedded in every project organization and reflect the corresponding components which have potential impacts on Green Building projects.
- The technique of Life Cycle Analysis (LCA) is considered as a useful method in finding external stakeholders for improving the environmental performance.

This chapter provides a theoretical foundation for the research problems addressed in this thesis. Details discussion will be presented in the following sections.

Figure 4.1 Procedures of Exploring Revolution Model and CSFs Frameworks of AEC Firms towards Green Building

4.3 Theoretical Foundations

The concepts of the “value chain and value system” provide useful frameworks for analyzing the construction process of Green Building projects. The “value chain and value system” frameworks are introduced as follows.

4.3.1. Value Chain

The concept of value chain was developed by Porter (1985). A value chain “disaggregates a firm into its strategically relevant activities in order to understand the behavior of costs and the existing and potential sources of differentiation”, where the main idea is to use it as an analysis tool for strategic planning. In order to conduct the value chain analysis, the company is split into two types of activities: primary (inbound logistic, operations, outbound logistics, marketing and sales, customer service) and support activities (procurement, technologic development, human resources, firm infrastructure) (Figure 4.2). Primary activities are those that are directly concerned with the physical creation, sale and delivery of a product or service. The goal of the primary activities is to produce value that exceeds the cost, thereby resulting in a profit margin. While support activities are those that provide the

background necessary for the effectiveness and efficiency of the firm. Every value activity employs purchased inputs, human resources and some form of technology to perform its function. Another important component is “margin”, which is the difference between total value and the collective cost of performing the value activities. All the primary and support activities aim for more margin. The value chain is not only a collection of independent activities but rather a collection of interdependent activities. Linkage can exist between primary activities, as well as, between primary and support activities. Competitive advantages can be also derived from the linkages between activities.

The value chain model represents the corporate internal environment (Bredin, 2004). It has been used as a powerful analysis tool for organizational strategic planning for nearly two decades now, which indicates that the value chain of a company is a useful tool in understanding and identifying crucial aspects to achieve competitive strengths and core competencies in the marketplace.

Figure 4.2 Value Chain (Porter, 1985)

4.3.2. Value System

The traditional value chain analysis strongly focuses on the internal resource of the organization and it tends to isolate the organization’s activities from its environment (Middendorp, 2005). According to McPhee and Wheeler (2006), focusing on the internal core activities of a firm is not enough to derive value in today’s firms. Porter

(1985) extended the concept of the value chain to the whole industry. A firm's value chain was part of a larger system that included the value chains of upstream suppliers and downstream channels and customers. Porter called this series of value chains the value system, shown in Figure 4.3. The total margin available is spread across suppliers, distributors and customers. A firm can enhance its profitability and competitive advantage not only by understanding its own value chain – from design to distribution – but also by understanding how the firm's value activities fit into the supplier's and customer's value chains (Li and Jenni, 2004).

Figure 4.3 Value System (Porter, 1985)

Porter's value chain and system models are very popular among academics, consultants and managers (Porter, 1985). The original purpose of value chain and system analysis is to identify competitive advantages and increase profit for the manufacturing industry, which is product-oriented. However, they pay little attention to green value generation and improvement which are gradually concerned in the project-oriented construction industry. In order to bridge the gap between traditional value-added activities and Green Building development, this research attempts to introduce two new concepts: "value chain framework for Green Building" and "value system framework for Green Building". They can provide powerful frameworks for extracting the major factors critical to the improvement of environmental performance for building projects. Based on these critical factors, the organization will know how to bring about internal changes and modify resources to achieve Green Building effectively and efficiently.

4.4 Value Chain Framework for Green Building

In order to extract critical activities of AEC firms to improve environmental

performance of building projects, the value chain framework for Green Building is introduced. In the following section, three basic components of the value chain framework for Green Building, value, primary activities, and support activities, are discussed in detail.

4.4.1. Value for Green Building

Identification and analysis of primary and support activities in the traditional value chain are based on the value. However, there are difficulties in providing a definition of value on which many people may agree. The value was defined by Porter as the amount buyers are willing to pay for what the firm provides. For construction, value means the satisfaction of clients (RSC, 2006). In order to gain a better understanding you need to be able to explicitly identify what your customers' (or end users') value is. Traditionally, the customers' requirements about the building projects are just cost, quality and schedule. Therefore, the design and construction stages only focus on cost, quality and time. However, in recent years, the sustainable performance of building projects becomes an important criterion for the satisfaction of clients, and it often serves as a crucial benchmark for assessing the performance of a project. Jerry (2007) stated "Sustainability is definitely part of values, and from a marketing standpoint it has been important to us". In this sense, sustainability can be treated as a source of values itself. Therefore, in this value chain framework for Green Building, instead of using profit margin as base for activities analysis, green performance of buildings will be employed as the objective of primary and support activities. Green Building rating systems can be used as a good indicator of Green Building performance. These systems have established various criteria for assessing environmental performance of buildings, which provide valuable references to this study.

Until now, lots of performance assessment tools have been developed. Examples include Building Research Establishment Environmental Assessment Method (BREEAM) (UK), Leadership in Energy & Environmental Design (LEED) (US), and Green Mark (Singapore). There are an unwieldy number of criteria and indicators that

introduce various ways of measuring various aspects of building performance (Lutzkendorf and Lorenz, 2005). A comprehensive listing of criteria of different assessment systems identified from the literature review is presented in Table 4.1.

Table 4.1 Lists of Criteria for Different Assessment Systems (Lee and Burnett, 2006; Todd *et al.*, 2001; Kimberly *et al.*, 2006)

Criteria	LEED	Green Mark	BREEAM	GBTTool	HK-BEAM	EcoProfile	ESCALE	EcoEffect
	U.S.	Singapore	U.K.		Hong Kong	Norway	France	Sweden
Energy	●	●	●	●	●	●	●	
Water	●	●	●	●	●	●	●	
Materials	●	●	●	●	●	●	●	●
Indoor environment	●	●	●	●	●	●	●	●
Outside environment	●			●	●	●	●	●
Site development	●	●	●	●	●	●	●	

Those with “●” are issues included in the corresponding scheme

Based on the analysis of criteria in different assessment methods, the environmental performance criteria of building projects can typically fall into six basic categories: energy, water, materials, indoor environment and outside environment (soil erosion, dust, harmful gases, noise, liquid effluents), as well as site development. Because “site development” is usually decided by planners, which is obviously beyond the control of AEC firms, this criterion will not be considered in the study. Based on the five environmental performance criteria of building projects, the primary and support activities for Green Building can be explored in detail.

4.4.2. Primary Activities for Green Building

Primary activities are directly concerned with the physical creation, sale and delivery of a product or service in the traditional value chain analysis. In the analysis of value chain framework for Green Building, primary activities, involved in the physical creation of the product (Green Building), are actually Green Building measures. In an

effort to address the environmental impacts of buildings, Green Building measures have attracted the attention of researchers and practitioners in different fields in recent years. Lots of sustainable materials and technologies have been applied in real practice. In considering the sustainability of buildings, the physical boundaries of Green Building measures are quite extensive and include the extraction of materials, the manufacturing of products, the assembly of products into buildings, the maintenance and replacement of systems, as well as the ultimate disposition of waste, building systems, and ultimately the building structure in all the life cycle stages of building (plan, design, construction, operation & maintenance, demolition) (Kiberta, 2007). Usually, AEC firms are only in charge of decisions in the design and construction stages. Therefore, within the control of AEC firms, only the activities, which can lead to significant improvement of Green Building performance in the design and construction stages, will be considered in this framework.

In broad terms, design stage includes all the processes before the commencement of constructing a building on site (Bao, 2003). Thus it includes architectural and structural design, the development of contract documents, and in some cases, includes bidding or negotiation, and award of the construction contract, which marks the transition into construction (Vanegas, 2003). The researchers for sustainable construction highlight the importance of design in order to achieve greater sustainability, because buildings or any other facility are the end product of all the design decisions taken at the outset of a project (Khalfan, 2001). The decisions making in this stage can influence the environmental performance of building in the areas of energy efficiency, water efficiency, material usage, indoor environment, and atmospheric considerations. Good design is at the heart of sustainable construction (Seah, 2008). There are many opportunities for improving project sustainability before any actions begin on site. Specific elements that should be considered include integrated building design (which takes into account of building form, building orientation, construction details, ventilation strategies, insulation, and passive solar design), the selection of heating and lighting systems and appliances within a building,

and the choice of building materials (Bao, 2003; Vanegas, 2003). Usually, the levels of building performance have been fixed at this point.

In the construction stage, the contractor only needs to follow detailed specifications to meet sustainable requirements set at the design stage. Therefore, Green Building measures in construction stage are often ignored. However, at present, more and more researchers realize substantial environmental impacts caused at the construction stage and more Green Building measures have been developed.

The construction stage is the bridge between concept and reality, which includes construction planning, execution, start-up and commissioning (Vanegas, 2003). Various environmental problems are related to the construction operations, such as substantial dust, noise, site disturbance, and indoor environmental quality, which may have significant, although generally short-term, local effects (Best, 1997). The recommendations, offering opportunities for increasing sustainability of projects, include erosion and sediment control, the choice of Green Building materials, sequencing work to minimize exposure of materials to potential contamination, waste minimization and recycling, commissioning, etc. (Bao, 2003).

Detailed Green Building measures in the design and construction stages are listed in the Table 4.2. It should be kept in mind that some Green Building measures can not be applied in buildings without the cooperation of designers and contractors.

Table 4.2 Green Building Measures in Design and Construction Stages (Sharon, 2002; Bao, 2003; Dione1 *et al.*, 2005)

Green Building criteria	Green Building measures	Stages of building life-cycle influenced (design/construction)
Energy efficiency	An integrated design (building orientation, building form, internal design, increased insulation and shading) with computer simulation tools	design
	Green roofing/Light colored roofing	design
	Efficient heating and cooling equipments and appropriate sizing	design

		Efficient lighting fittings	design
		Solar water heating	design
		Sub-metering systems	design
		Solar photovoltaics	design
		Advanced on-site construction equipments	construction
		Energy management systems	construction
		Commissioning	construction
Water efficiency		On-site gray water/rainwater/excess groundwater reuse	design
		Low-water-use fixtures and water-free urinals	design
		Sub-meters	design
Materials		Innovative design and construction techniques, i.e., design for demolition, prefabricate building components.	design/construction
		Use local products and materials	design/construction
		Use waste and highly-recycled-content materials	design/construction
		Use reusable components and recyclable materials	design/construction
		Use certified sustainable materials	design/construction
Indoor quality	air	Design/construction integration measures	design/construction
		Control pollutant sources (i.e. avoid materials that will off gas pollutants)	design/construction
		Install carbon-dioxide monitors	design
		Protect building materials from the elements during construction	construction
		Implement construction IAQ management plan	construction
		Computer-aid simulation of indoor environment	design
Outdoor environment (Soil erosion, Dust, Harmful gases, Noise, Liquid wastes)		Silt Fence	construction
		Diversion Ditches	construction
		Construction Entrances	construction
		Temporary matting	construction
		Site restoration with native plants	construction
		Permeable paving (i.e. riprap dissipation pads)	construction
		Static crushing/chemical breaking	construction
		Wet excavation/drilling	construction
		Having vehicles stay on established routes, and keep these routes moist/Washing transporting equipment/Reducing vehicle speed and do not overload haul vehicle	construction
		Careful planning to keep the disturbed	construction

area to a minimum	
Hydraulic piling equipment	construction
Electric machine	construction
Bolt/pressure connection	construction
Poison-free solvent	construction
Laser cutting	construction
Soundproof room and wall	construction
biological waste treatment systems	construction
Night shift	construction

4.4.3. Support Activities for Green Building

The support activities only affect the implementation of Green Building to the extent that they affect the performance of primary activities. They can maximize sustainability of buildings based on present technological conditions. In order to enable and improve the performance of the primary activities, support activities should be identified and analysis in detail.

4.4.3.1. Support Organizational Activities

The relevant level of support activities is a firm's management strategies (the business unit) in the manufacturing industry. This indicates that the management activities at the firm's level can affect value addition for the product-oriented company. For the building industry, which is project-oriented, construction firms may support many projects simultaneously. In this sense, the project performance is somewhat influenced by management activities of the central company organization. However, most research papers are lack of emphasis on the organization behind the projects. In the value chain framework for Green Building, the support organizational activities, which can affect environmental performance of building project, should be explored. However, the classification of support activities at firm's level in traditional value chain is too broad, and may obscure important sources of influence factors. Consequently, more in-depth investigations of support organizational activities should be conducted.

In order to have a clear and detailed understanding of the support activities, current organization management strategies should be uncovered firstly. These management activities provide insight to the fundamental components of an organization, which are sources of support activities for Green Building projects. Resource-Based View (RBV) and Cheah's Conceptual Model are two well known theories, which can help investigate competitive advantages of firms based on exploring the firm's resources. Although they are usually used for strategy analysis for the firm, they can help investigate internal resources at firm's level. Therefore, in this paper, the strategic theory of RBV and Cheah's Conceptual Model are used, which can lay the groundwork for identifying the supporting organizational factors.

(1) Resource-Based View

Firm resources are commonly controlled by the firm that enable the firm to conceive and implement strategy and improve its efficiency (Daft, 1983; Penrose, 1959). The Resource-Based View (RBV) looks at the internal assets (resources) as a foundation for value strategy (Rechenthin, 2004). The resources may be people, financial, brand names, technology, machinery, land, contracts, managerial skills, and similar assets (Rechenthin, 2004). According to Man (2001), resources in a firm can be classified into financial, physical, human, organizational and technological resources. Barney (1991) described firm resources as attributes that: "include all assets, capabilities, organizational processes, firm attributes, information, and knowledge", such as assets, organizational characteristics, processes, aptitudes, information and knowledge controlled by the company and its employees. Generally, most researchers agreed that internal assets can be classified into tangible and intangible resources. Tangible resources include financial resources, physical resources, human resources and organizational resources. Intangible resources include technological resources, resources for innovation and reputation (Barney, 1991). The RBV is a conceptual framework for understanding firm-level growth using resources as building blocks.

(2) Cheah's Conceptual Model

Cheah (2002) classified the internal resources of large global engineering and construction firms into seven strategic fields: business strategy, operational strategy, IT strategy, marketing strategy, technology strategy, human resource, and financial strategy. Figure 4.4 shows the seven strategic fields inside corporate strategy. Two internal mechanisms of organization (organizational structure and culture) were also identified, as shown in Figure 4.5. Any discussions of corporate strategy should always parallel the internal mechanisms of an organization. These issues exist at the corporate level and are embedded in very lifeblood of the organization, and hence reflect the corresponding firm-specific resources and capabilities (Cheah and Gurvin, 2004). As a corollary, organizational leaders should treat the seven strategic fields and the two internal mechanisms of organization as variables building blocks of corporate strategy – these lie within the boundary and can be controlled by the firm (Cheah and Gurvin, 2004).

Figure 4.4 Seven Strategic Fields of Corporate Strategy in Cheah's Model (Cheah and Gurvin, 2004)

Figure 4.5 Overview of Cheah's Conceptual Model (Cheah and Gurvin, 2004)

The identification of the organizational behavior provides insight to the fundamental components of an organization, which can be controlled by the firm. These components provide a means to promote organization effectiveness and company performance, which have potential effects to help improve environmental performance of building projects.

Furthermore, the process of delivering Green Building projects is more difficult than delivering traditional projects. It often requires higher construction standards, advanced simulation and analysis, more complex technology, and the use of new and unfamiliar materials. The materials and technologies are also updated quickly. As a result, it requires qualified employees in the company, and providing regular training and education for them. Besides, the company is better providing incentives and compensation policies so as to encourage the application of more sustainable technologies and ideas. In summary, the supporting organizational activities can be classified into: financial resources, technical competency, experience and knowledge in Green Building, training and education, qualified employees, incentives and compensation policies and system, company image, R&D capability, innovation capability, organizational structure and organizational culture.

4.4.3.2. Support Project Management Activities

The traditional value chain analysis is established based on the manufacturing industry, which is product-oriented. Thus, the support activities are mainly at firm's level. However, building industry is a project-oriented industry. Construction firms sometimes may have many simultaneously ongoing building projects and each project is commonly led by one project team. Therefore, the project management activities play an essential role on the performance of building project, including the environmental performance. Effective project management is especially critical for the successful accomplishment of sophisticated projects (Isik, 2009). A project team typically consists of players with diverse roles, such as an architect, structural and mechanical engineers and a project manager. Usually the team is gathered provisionally just for a single project. Hence, each individual has to re-adjust to a new team for every project. This re-adjustment process takes time and it is sometimes difficult to achieve due to structural or attitudinal problems within organizations or members of organizations (Rowlinson, 2004). In essence, until now, a large body of research has been conducted to investigate project management factors affecting the performance of projects. These project management activities should be systematically explored firstly, for the purpose of identifying current components of project organization. These components represent some features inherent in project organizations, which may have potential impacts on the environmental performance of building projects.

Sayles and Chandler (1971) identified the following five Critical Success Factors (CSFs) for a project: project manager's competence, scheduling, control systems and responsibilities, monitoring and feedback, and continuing involvement in the project. Ashley (1987) concluded that the success of a construction project is repeatable in achieving cost effectiveness and gaining a competitive position. They identified the most important success factors for construction projects: planning effort, project team motivation, project manager goal commitment, scope and work definition, control

systems and project manager technical capabilities. Pinto and Slevin (1989) studied CSF for R&D projects and identified ten CSFs: project mission, top management support, project schedule/plans, client consultation, personnel recruitment, technical tasks, client acceptance, monitoring and feedback, communication, trouble-shooting, characteristics of the project team leader, power and politics, environmental effects, and urgency. Munns and Bjeirmi (1996) identified the project management success factors including commitment to complete the project, appointment of a skilled project manager, adequate definition of the project, correctly planning the activities in the project, adequate information flow, accommodation of frequent changes, rewarding the employees, and being open to innovations. Chan *et al.* (2001) investigated a set of project success factors for design-build (DB) projects. They identified the six most significant project success factors from 31 factors. They are project team commitment, client's competencies, contractor's competencies, risk and liability assessment, end-users' needs, and constraints imposed by end-users. At last, they found project team commitment, client's competencies, and contractor's competencies to be the most important factors for a successful project outcome. Chan *et al.* (2004) reviewed the literature related to CSFs in seven major management journals and proposed a new conceptual framework for factors affecting project success. They categorized success factors into five main groups: project-related factors, project procedures, project management actions, human-related factors, and external environment. Each group was dependent on some specific attributes. For example, the project management actions depended on attributes: the communication system, control mechanism, feedback capabilities, planning effort, organization structure, safety and quality assurance program, control of subcontractors' works, and finally the overall managerial actions.

Review of the literature suggests that there are a large number of factors that influence the success of project implementation. However, some factors are beyond the control of AEC firms (e.g. climate conditions and client's competencies). Further discussion on these factors is not so much meaningful because it is hard to attempt to manipulate.

In this study, only the project management factors within the control of AEC firms are considered. Table 4.3 summarizes eleven factors for successful projects suggested by existing literature.

Table 4.3 A List of Critical Project Management Factors from Previous Literature

Critical project management factors	Reference
Support from senior management	[Pinto and Slevin, 1989]; [Pinto and Slevin, 1988]; [Pinto and Slevin, 1992]; [Schultz <i>et al.</i> , 1987]; [Cleland and King, 1983]; [Locke, 1976]; [Iyer and Jha, 2005]; [Chua <i>et al.</i> , 1999]; [Jha <i>et al.</i> , 2007]; [Belassi <i>et al.</i> , 1996]; [Fortune <i>et al.</i> , 2006]; [Nguyen <i>et al.</i> , 2004]; [White and Fortune, 2002]
Skilled designers	[Chua <i>et al.</i> , 1999]
Skilled project managers	[Pinto and Slevin, 1989]; [Ashley <i>et al.</i> , 1987]; [Chan <i>et al.</i> , 2001]; [Jaselskis and Ashley, 1991]; [Wit, 1988]; [Sayles and Chandler, 1971]; [Munns and Bjeirmi, 1996]; [Baker <i>et al.</i> , 1983]; [Locke, 1976]; [Iyer and Jha, 2005]; [Chua <i>et al.</i> , 1999]; [Jha <i>et al.</i> , 2007]; [Belassi <i>et al.</i> , 1996]; [Tishler <i>et al.</i> , 1996]; [Fryer, 1985]; [Fortune <i>et al.</i> , 2006]; [Nguyen <i>et al.</i> , 2004]; [Kerzner, 1987]; [Rubin and Seeling, 1967]
Trouble-shooting	[Pinto and Slevin, 1989]; [Pinto and Slevin, 1988]; [Pinto and Slevin, 1992]; [Jaselskis and Ashley, 1991]; [Belout <i>et al.</i> , 2004]
Project team motivation	[Ashley <i>et al.</i> , 1987]; [Wit, 1988]; [Munns and Bjeirmi, 1996]; [Chua <i>et al.</i> , 1999]; [Nguyen <i>et al.</i> , 2004]
Commitment of all project participants	[Ashley <i>et al.</i> , 1987]; [Chan <i>et al.</i> , 2001]; [Wit, 1988]; [Munns and Bjeirmi, 1996]; [Baker <i>et al.</i> , 1983]; [Locke, 1976]; [Chua <i>et al.</i> , 1999]; [Jha <i>et al.</i> , 2007]; [Fortune <i>et al.</i> , 2006]; [Nguyen <i>et al.</i> , 2004]; [Kerzner, 1987]
Strong/detailed plan effort in design and construction	[Pinto and Slevin, 1989]; [Ashley <i>et al.</i> , 1987]; [Jaselskis and Ashley, 1991]; [Chan <i>et al.</i> , 2001]; [Wit, 1988]; [Munns and Bjeirmi, 1996]; [Baker <i>et al.</i> , 1983]; [Fortune <i>et al.</i> , 2006]; [Nguyen <i>et al.</i> , 2004]
Adequate communication channels	[Pinto and Slevin, 1989]; [Pinto and Slevin, 1988]; [Pinto and Slevin, 1992]; [Jaselskis and Ashley, 1991]; [Jergeas <i>et al.</i> , 2000]; [Chan <i>et al.</i> , 2001]; [Munns and Bjeirmi, 1996]; [Cleland and King, 1983]; [Chua <i>et al.</i> , 1999]; [Ling <i>et al.</i> , 2008]; [Fortune <i>et al.</i> , 2006]; [Nguyen <i>et al.</i> , 2004]; [White and Fortune, 2002]; [Belout <i>et al.</i> , 2004]; [Clarke, 1999]; [Igal <i>et al.</i> , 2003]
Effective control, such as monitoring and updating plans	[Pinto and Slevin, 1989]; [Pinto and Slevin, 1988]; [Pinto and Slevin, 1992]; [Ashley <i>et al.</i> , 1987]; [Jaselskis and Ashley, 1991]; [Chan <i>et al.</i> , 2001]; [Wit, 1988]; [Sayles and Chandler, 1971]; [Baker <i>et al.</i> , 1983]; [Locke, 1976]; [Iyer and Jha, 2005]; [Chua <i>et al.</i> , 1999]; [Fortune <i>et al.</i> , 2006]; [Nguyen <i>et al.</i> , 2004]

	<i>al.</i> , 2004]; [White and Fortune, 2002]; [Belout <i>et al.</i> , 2004]
Effective feedback	[Pinto and Slevin, 1989]; [Pinto and Slevin, 1988]; [Pinto and Slevin, 1992]; [Jaselskis and Ashley, 1991]; [Chan <i>et al.</i> , 2001]; [Sayles and Chandler, 1971]; [Iyer and Jha, 2005]; [Chua <i>et al.</i> , 1999]; [White and Fortune, 2002]
Adequate financial budget	[Baker <i>et al.</i> , 1983]; [Cleland and King, 1983]; [Phua and Rowlinson, 2004]; [Chua <i>et al.</i> , 1999]; [Fortune <i>et al.</i> , 2006]; [Nguyen <i>et al.</i> , 2004]; [White and Fortune, 2002]

These factors summarized in Table 4.3 are usually identified as important success factors for improving project performance in terms of cost, time and quality. They exist and are embedded in every project organization and reflect the corresponding components which have potential impacts on Green Building projects. For example, “trouble-shooting” can be called problem-solving. During the process of design and construction stages, some unexpected operational and technical problems, which can cause pollution, may arise. If the project team can generate fast solutions, it can greatly improve the environmental performance of building projects. Therefore, effective and efficient trouble-shooting is very important to successfully implement Green Building projects. Feedback is a mechanism for operators to inform the decision-makers of how the planned activities are going, for instance, from project managers to designers or from builders to project managers. “Effective feedback” can give decision-makers a chance to make timely adjustments to continually improve environmental performance. Especially, Green Buildings often incorporate innovative techniques and management methods, which make effective feedback indispensable for a project organization.

Besides these factors, Green Building has some common key characteristics, which can also affect the project management activities. The detailed analysis of these common characteristics of Green Building and their effects on the project management activities are discussed as follows:

(1) High initial cost

Building features that are environmental friendly are usually more costly. Thus, green projects usually require high capital outlay and also are prone to cost increase during the course of construction. The availability of “adequate financial

budget” is especially necessary for the high initial capital outlay required and also serves to cater for any unexpected cost increase during the construction stage (Yang, 2006). Currently a number of financial institutions are offering various financial assistance schemes for Green Buildings. Roodman and Lenssen (1995) reported many examples of financial institutions giving preferential lending rates for the construction of Green Buildings, and water and electricity supply utilities offering fee rebates on payment for services used in water and energy efficient buildings. In line with these schemes, “innovative financial approaches” can be developed, which can help the project organization get the low interest load from the bank and pay the load using the underlying project revenues from energy and water conservation in the operation stage. In this case, it is seemly that effective financing methods would complement the successful implementation of Green Building.

(2) High environmental requirements

Environmental requirements on project site are significantly more stringent for Green Buildings (Pulaski *et al.*, 2006). In order to enhance the outdoor environmental performance on site, replacing the obsolete machinery and equipment by advanced ones is an important means (Bao, 2003). Furthermore, computer simulation can be used through all of the process of building design to improve the quality of outdoor and indoor physical environment, thermal performance of the envelope and the energy system with the idea of ‘sustainable design by simulation at different stages’ (Zhu *et al.*, 2004). More accurate simulation software should be developed and applied to help make decisions, such as Building for Environmental and Economic Sustainability (BEES), Building Energy Standard (BEST), the Environmental Resource Guide, LCExplorer and SimaPro. Besides, new knowledge related to the environmental field is developing at a very rapid pace and the environmental requirements for Green Buildings become rigorous over time. More and more innovative technologies, such as prefabrication and installation technologies, integrated design (Syal *et al.*, 2007) and sustainable materials, should be incorporated into

the building construction to improve the environmental performance. Additionally, effective innovative management method can help project team minimize pollution to the environment from the existing facilities (Khalfan, 2002). Currently, there are various management systems developed for achieving these objectives, such as energy management system (Patrick *et al.*, 1993), environmental impact assessments and waste management (Bao, 2003).

(3) Complex process

The process of delivering Green Building projects often requires more design iterations, advanced simulation and analysis, additional site precautions, and the use of new and unfamiliar materials, which is typically more complicated than those in traditional projects (Pulaski *et al.*, 2006). Cooperation between decision-makers within the project organizations is crucial to effectively manage Green Building projects (Syal *et al.*, 2007; Bakens, 2003). The most effective ways to solve these complicated process works are: cooperation between architects and engineers (Zhu *et al.*, 2004), designers' involvement in the construction stage (Chan, 2002), as well as, contractors' involvement in the design stage (Pulaski *et al.*, 2006).

Based on the analysis of the key characteristics of Green Building projects, eight more project management factors were identified. Besides, for better performance of building project in terms of cost, schedule and quality, "effective control, such as monitoring and updating plans" are required as summarized in Table 4.3. Accordingly, in order to improve the environmental performance of building projects, "effective environmental compliance and auditing programs" should be undertaken to monitor the work being performed and help identify environmental pollutions associated with the work activities. In sum, nineteen project management factors contributing to the success of Green Building projects are proposed and listed in the following section.

Figure 4.6 Value Chain Framework for Green Building

Based on exploration of the three important components (value, primary activities and support activities for Green Building), the value chain framework for Green Building is presented in the Figure 4.6. As shown in Figure 4.6, the support activities are composed of two categories, one is support organizational activities, the other is the support project management activities. The relationships of them are illustrated in Figure 4.6, which indicates one organization can undertake several projects simultaneously. Every activity in the two categories must be performed to some extent in order to improve the environmental performance of building project effectively and efficiently.

4.5 Value System Framework for Green Building

The value chain framework for Green Building only focuses on internal sources of AEC firms, which can help improve the environmental performance of building projects. Although improvements within AEC firms are prerequisite to reduce environmental impacts of buildings, by itself it is not enough. This is the greatest challenge faced by the building industry as a whole. Therefore, the concept of value chain framework for Green Building should be extended beyond AEC firms in the

design and construction stages and applied to all the life cycle stages of building industry, which can be defined as value system framework for Green Building.

Recently, researchers pay more attention on the life cycle analysis (LCA) method, which is considered as the most comprehensive and appropriate method to analyze the activities contributing to the sustainability of building. The life cycle of Green Building includes from planning and design, to construction, use, refurbishment and reuse, demolition, reuse and recycling. In order to bring improvements within the built environments, the building industry has to pay attentions to all the activities carried out in each of the above mentioned phases (Suzy, 2003). The different stages of a building's life cycle are handled by different stakeholders. Adjacent stakeholders and external linkages can lead to significant reduction of environmental impacts of building projects. This indicates that the successful implementation of Green Building requires the communication and collaboration between AEC firms and other stakeholders. Therefore, AEC firms should establish good relationships with other stakeholders in the value system framework for Green Building, which includes qualified/certified materials and products suppliers, advanced equipment suppliers, qualified/certified sub-contractors, green consultants, qualified/certified planers, clients, qualified/certified demolition contractors, finance institutions and government. These relationships are also within the realm of control of AEC firms and have been regarded as external resources of AEC firms. Based on the above analysis, the value chain and value system frameworks for Green Building can be established in Figure 4.7.

Figure 4.7 Value Chain and Value System Frameworks for Green Building

The value chain and value system frameworks for Green Building provide the theoretical basis for exploring the critical factors to improving the environmental performance. The Generic Revolution Model and Critical Success Factors (CSFs) framework of AEC firms established based on the analysis value chain and value system frameworks for Green Building are discussed in the following sections.

4.6 Generic Revolution Model of AEC Firms towards Green Building

Based on the introduction and detail analysis of “value chain framework and value system frameworks for Green Building”, a revolution model for the AEC firms towards Green Building, which explores all the possible ways within the control of AEC firms having impacts on environmental performance, is created, as shown in Figure 4.8.

Figure 4.8 Revolution Model for AEC Firms towards Green Building

As is illustrated in the Figure 4.8, environmental performance of buildings is the main objective of design and construction stages. The primary and support activities (including support organizational activities and support project management activities), as well as some external relationships all contribute to the improvements environmental performance of buildings. It can assist AEC firms in the identification of critical activities and understanding the whole process for the implementation of Green Building.

At present, most of the researches for Green Building strongly focus on the primary activities (Green Building measures), which can help improve environmental performance of buildings technologically. In fact, in line with Green Building measures to maximize reducing environmental impacts of building projects, construction organizations should reconsidered the current management practices (including support organizational activities, project management activities within AEC firms and AEC firms' external relationships). However, little work has been done to investigate management activities for Green Buildings, which also plays an important role for the successful implementation of Green Building. This study

therefore aims to fill this gap. A more detailed analysis that focuses on these areas is fully discussed in the following research work.

4.7 Generic Critical Success Factors (CSFs) Framework of AEC Firms towards Green Building

With the aid of previous studies discussed above in this chapter, a generic Critical Success Factors (CSFs) framework is developed, which establishes the theoretical basis for this study. It postulates that the success of a Green Building project is a function of project management factors, organizational factors and external relationships, and all these factors are within the control of AEC firms, as shown in Figure 4.9. By setting out the relationships between the independent variables and dependent variables, this framework can be used as a guide to facilitate prioritizing critical factors for one specific Green Building rating system. The revolution of AEC firms towards Green Building can be well understood by exploring the detailed CSFs. Green Mark is the certification system for Green Building in Singapore. In order to examine how this proposed framework can be applied in the specific context, these critical management factors are ranked according to successful implementation of Green Mark certified projects in Chapter 5 through analyzing the data collected from a questionnaire survey.

Figure 4.9 Generic CSFs Framework of AEC Firms towards Green Building

4.8 Chapter Summary

From the basic theories of value chain and value system, the value chain and value system frameworks for Green Building are introduced. A Generic Revolution Model for AEC firms towards Green Building is established through the detail analysis of value chain and value system frameworks for Green Building. In this model, environmental performance of building projects is the objective for the design and construction stages. The full range of activities within control of AEC firms (including the primary activities, support activities, as well as some external relationships) required to improve the sustainability of buildings are described. In the following section, a generic CSFs framework, including support organizational activities, project management activities and AEC firms' external relationships, are established. These CSFs have been totally and systematically identified and appropriately explained based on the understanding of value chain and value system frameworks for Green Building. However, the identification of these critical management factors in this chapter is considered from a theoretical point of view. In order to demonstrate

how this framework can be applied according to one specific Green Building assessment system based on empirical studies, the relative importance of these critical factors for obtaining Green Mark certification in Singapore is investigated in Chapter 5 and Chapter 6.

Chapter 5 Research Findings and Discussion

5.1 Introduction

This chapter focuses on presentation and discussion of the data analysis results to explore the Critical Success Factors (CSFs) for obtaining Green Mark certification so as to examine the application of generic CSFs framework in real practice. The structure of this chapter is organized as follows: firstly, the general information of the survey is explained after summarizing the questionnaires. Secondly, the descriptive analysis of these factors and their reliability test are presented. After that, the critical project management factors, organizational factors and firms' external relationships for delivering Green Mark certified projects in Singapore are explored using factor analysis and multiple regression analysis. Then the research findings are discussed. Finally, the specific CSFs framework of AEC firms for Green Mark certified projects is established according to the research findings.

5.2 General Information of the Survey

In this part, the response rate is firstly presented. Then, the profile of respondents is described to ensure the validity of the data obtained from them. After that, the information of their companies, as well as characteristics of the sample projects are explained.

5.2.1. Response Rate

The questionnaire survey was conducted in Singapore. The target population of the questionnaire survey is all the professionals and decision-makers in the industry, including project managers, architects, engineers and consultants, who have experience in the building industry in Singapore and have been involved in Green Mark certified projects. Obviously, the random sampling can not be used in this study,

since it usually gets a very low response rate. The strategy for sample selection was presented in Chapter 3. The final questionnaire was sent out in May 2009 followed by reminders sent to the respondents who had not replied. Out of the 89 questionnaires that were sent out, 42 were received by the end of 2009. Five responses were eliminated due to a high degree of incompleteness. Consequently, this study was based on 37 valid replies from the respondents who had experiences with Green Mark certified projects. Considering the limited number of Green Mark projects completed in Singapore in recent years, 37 responses from experienced experts could be deemed representative. Besides, this agrees with the suggestion by many researchers that a minimum sample size of 30 is considered representative for any group (Sproull, 1995; Ott and Longnecker, 2001). The effective response rate was about 41.6%, higher than the average response rate 25% for questionnaire surveys for Singapore's construction industry (Tan, 1995).

5.2.2. Profile of Respondents

Table 5.1 summarizes the designations of the respondents in the survey. It indicated that the largest group of the respondents belongs to senior management personnel, *i.e.*, directors and presidents (43.2%). Project managers, department managers, general managers and operation managers account for 40.5% of the respondents. Designers, including architects and engineers, account for 16.2%.

Table 5.1 Respondents' Designation

Respondents' designation	Frequency	Percent (%)	Cumulative percent (%)
Architect	5	13.5	13.5
Department manager	3	8.1	21.6
Director	15	40.5	62.2
Engineer	1	2.7	64.9
General manager	2	5.4	70.3
Operation manager	1	2.7	73.0
President	1	2.7	75.7
Project manager	9	24.3	100.0
Total	37	100.0	

The respondents' working experiences in the building industry in Singapore ranged from 5 to 42 years, with 19.8 years as the average (Table 5.2). 32.4% of the respondents have 16 to 20 years of experience, which is the major group. None of the respondents has less than 5 years of working experience.

Table 5.2 Respondents' Working Experience in Singapore's Building Industry

Years of experience in Singapore's Construction	Nos. of respondent	Percent (%)	Average
5-10	7	18.9	
11-15	4	10.8	
16-20	12	32.4	
21-25	6	16.2	19.8
26-30	4	10.8	
>30	4	10.8	
Total	37	100.0	

As shown in Table 5.3, all the respondents have been involved in Green Mark certified projects before, while half of them (51.3%) have participated in more than three Green Mark certified projects in Singapore.

Table 5.3 Respondents' Working Experience in Green Mark Certified Projects

Nos. of Green Mark projects	Frequency	Percent (%)	Cumulative percent (%)
1	5	13.5	13.5
2	6	16.2	29.7
3	7	18.9	48.6
>3	19	51.3	100.0
Total	37	100.0	

It can be seen from the respondents' profiles, a majority of them are middle or senior managers, with extensive experience in the building industry and the Green Mark certified projects. Data collected from these people should be representative and reliable. Additionally, among the 89 professionals, 13 are certified Green Mark managers and 10 of them responded to the survey request, with a response rate of 76.9%. Comparing to the overall response rate of 41.6%, the high response rate of the certified Green Mark managers may reflect their higher interest in the study of Green Mark certified projects, which could also indicate their strong commitment towards sustainability of construction industry in Singapore. Their participation in the questionnaire survey also ensure the validity of the data.

5.2.3. Respondents' Firms

Table 5.4 Number of Permanent Employees in Respondents' Firms

Firm Size by Employment	Number of Firms	Percent (%)	Average number of Employees
<50	0	0.00	
50-100	11	29.7	
100-200	7	18.9	
201-300	7	18.9	211
301-400	7	18.9	
>400	5	13.5	
Total	37	100.0	

Table 5.4 summarizes the number of permanent employees in respondents' firms where he or she is affiliated, which can be used to measure the size of these firms. According to the International Finance Corporation's classification to examine the structure of Singapore's construction industry, most of the construction firms in

Singapore are small and medium-sized firms and 92% of the total number of enterprises employed fewer than 50 persons (Goh, 2007). In this survey, all the respondents' firms have more than 50 permanent employees and the average number of employees is 211 for the respondents' firms. This means the firms for running Green Building projects are relatively large firms in Singapore. The possible reason maybe that: since Green Building is relatively new in Singapore, the implementation of Green Building needs high technological and management approaches, as well as advanced equipments. It may therefore be more practical for larger firms, which have enough human, technical and financial resources to implement.

Table 5.5 Practice of the Respondents' Firms Certified with Environmental Management System

Certified with Environmental Management System	Number of Firms	Percent (%)
Yes	27	73.0
No	10	27.0
Total	37	100.0

ISO 14000, an international standard, is suggested as a tool for construction companies to develop an effective EMS and, thus ensure environmental sustainability in construction (Yeo, 2004). Among these firms, 73% have been certified with ISO 14000 series, as summarized in Table 5.5. Actually, in Singapore, the Building and Construction Authority (BCA) has made it mandatory for contractor undertaking public projects to be ISO 14000 certified by 2004 (Khoo, 2002). However, only a mere handful of construction firms are ISO 14000 certified as compared to the total number of construction firms in Singapore. Until November 2005, 86 construction and construction-related firms in Singapore have been certified (Chun, 2006). That indicates that ISO 14000 certified firms have a major responsibility for environmental management on construction projects in order to minimize adverse impacts and are more likely undertaking Green Mark certified projects.

5.2.4. Characteristics of the Sample Projects

Table 5.6 Characteristics of Projects

		Category	Frequency	Percent (%)
Nature of Project		New Construction	37	100
		Renovation	0	0
		Total	37	100
Building Type		Residential	10	27.0
		Non-residential	27	73.0
		Total	37	100
Type of client		Private	31	83.8
		Public	6	16.2
		Total	37	100
Bidding Procedure		Selective	23	62.2
		Negotiation	3	8.1
		Open	11	29.7
		Total	37	100
Procurement Method		Design-build	20	54.1
		General contracting	5	13.5
		Design-bid-build	4	10.8
		Develop & construct	4	10.8
		Management contracting	3	8.1
		Others	1	2.7
		Total	37	100
Contract type		Lump sum	33	89.2
		Unit price	2	5.4
		Gross maximum price	2	5.4
		Total	37	100

The identification of controllable critical management factors for the successful completion of Green Mark certified projects in this study was based on a comprehensive database derived from the survey of 37 Green Mark certified building projects in Singapore. Table 5.6 shows the characteristics of these Green Mark certified projects reported by the respondents. As shown in Table 5.6, all these buildings are new constructions in Singapore. In terms of building types, 27 buildings are non-residential, and the other 10 are residential buildings. The buildings in this study are constructed mainly for private developers (83.8%). Actually, not only the Green Mark certified projects in this study, the majority of Green Mark certified

projects in Singapore are done by private sectors, even before the compulsory requirement of Green Mark, which indicates the great demand of Green Buildings in Singapore. It can also be observed from Table 5.6 that the majority of the contracts are “Lump sum fixed price” contracts (89.2%), of which most of these projects are awarded through selective bidding and negotiation (70.3%) and delivered generally through “Design-Build” method (54.1%). This suggests that AEC firms, which intend to expand their businesses into Singapore’s Green Mark projects market, need to have good international reputation and network with existing AEC enterprises in Singapore in order to be invited to bid.

5.3 Data Interpretation for Major Research Factors

This section mainly converts the responses gathered from the questionnaire survey into quantitative measures that are suitable for further analysis. The factors include three main parts, namely, project management factors, organizational factors and firms’ external relationships. In the following sub-sections, the mean and standard deviation of these factors are first presented. After that, the reliability analysis on the survey data is carried out to examine the quality of data.

5.3.1. Research Factors

5.3.1.1. Measurements of the Project Management Factors

Table 5.7 Scale of Measurement, Mean and Standard Deviation of Project Management Factors

Project management factors	Scale of measurement	Mean	Median	Std. Deviation
1. Support from senior management	1-5	4.49	5.00	0.692
2. Skilled designers	1-5	4.00	4.00	0.667
3. Skilled project managers	1-5	3.89	4.00	0.737
4. Trouble-shooting	1-5	3.65	4.00	0.633
5. Project team motivation	1-5	3.78	4.00	0.722
6. Commitment of all project participants	1-5	4.11	4.00	0.809
7. Cooperation between architects and engineers	1-5	4.22	4.00	0.712
8. Designers involved in construction stages	1-5	3.81	4.00	0.739
9. Contractors involved in design stages	1-5	3.43	4.00	1.259
10. Strong/detailed plan effort in design and construction	1-5	3.86	4.00	0.822
11. Adequate communication channels	1-5	3.86	4.00	0.713
12. Effective environmental compliance and auditing programs	1-5	3.62	4.00	0.758
13. Effective feedback	1-5	3.38	3.00	0.758
14. Advanced machinery and equipment	1-5	3.35	3.00	0.889
15. Effective and efficient software development and application	1-5	3.054	3.00	0.780
16. Innovative management approaches	1-5	3.35	3.00	0.949
17. Innovative technological approaches	1-5	3.54	3.00	0.767
18. Innovative financing methods	1-5	2.91	3.00	0.954
19. Adequate financial budget	1-5	3.65	4.00	0.919
Size of sample adopted: N=37				

Statistical means and standard deviations of project management factors were

computed. As shown in Table 5.7, the mean values of almost all the project management factors are higher than the mid-point of the scale. It implies that the project management of Green Mark certified building projects in Singapore is very well-organized in terms of these aspects. The main value of “innovative financing methods” is 2.91 (on a scale of 1 to 5), which is the lowest mean score among the factors. It indicates most projects follow the traditional financing procedures and methods. Among all the factors, “support from senior management” has the highest mean score, which indicates most Green Mark certified projects can get strong support from the firms. The resources and abilities of AEC firms play an important role to improve the environmental performance of building projects.

5.3.1.2. Measurement of the Organizational Factors

Firms’ performance can be measured by financial strength, technical competency, experience and knowledge in Green Building, training and education, qualified employees, incentives and compensation policies and system, company image, R&D capability, innovation capability, organizational structure and organizational culture. The scale of measurement, mean, standard deviation, and median of these factors are listed in Table 5.8.

At first glance, the descriptive statistics of these factors may imply that: “technical competency” is more extensively developed and “R&D capability” is a little weak as compared with other organizational factors. The main value of formalization is 5.97 (on a scale of 0-10) and this indicates that on average, AEC firms in Singapore are more likely to design formalized rules and procedures to govern some of their operational activities. However, the mean value of centralization is 3.73 and lower than the mid-point of the scale (on a scale of 0-10), which suggests a relatively weak degree of centralization for the structure of AEC firms in Singapore. As for the organizational culture, it is difficult to draw obvious conclusions since the mean and median are close to the min-point of the respective scales.

Table 5.8 Scale of Measurement, Mean and Standard Deviation of the Organizational Factors

Organizational Factors	Scale of Measurement	Mean	Median	Std. Deviation
1. Financial strength	1-5	4.21	4.00	0.787
2. Technical competency	1-5	4.38	4.00	0.639
3. Experience and knowledge in Green Building	1-5	4.05	4.00	0.815
4. Training and education	1-5	3.81	4.00	0.811
5. Qualified employees	1-5	4.00	4.00	0.782
6. Incentives and compensation policies and system	1-5	3.37	3.00	0.758
7. Company image	1-5	4.16	4.00	0.602
8. R&D capability	1-5	3.24	3.00	0.925
9. Innovation capability	1-5	3.68	4.00	0.973
10. Organizational structure Formalization	0-10	5.97	6.00	2.500
Organizational structure Centralization	0-10	3.73	3.00	2.854
11. Organizational culture	0-9	5.05	5.00	2.000
Size of sample adopted: N=37				

5.3.1.3. Measurement of the Firms' External Relationships

The external relationships of AEC firms mainly include qualified/certified materials and products suppliers, advanced equipment suppliers, qualified/certified sub-contractors, good green consultants, qualified/certified planers, clients, qualified/certified demolition contractors, finance institutions and government. The scale of measurement, mean, standard deviation, and median of these relationship factors are summarized in Table 5.9.

Table 5.9 Scale of Measurement, Mean and Standard Deviation of Firms' External Relationships

Firms' External Relationships	Scale of Measurement	Mean	Median	Std. Deviation
1. Relationship with qualified/certified materials and products suppliers	1-5	3.76	4.00	1.011
2. Relationship with advanced equipment suppliers	1-5	3.46	4.00	1.016

3. Relationship with qualified/certified sub-contractors	1-5	3.86	4.00	0.822
4. Relationship with good green consultants	1-5	3.70	4.00	1.024
5. Relationship with qualified/certified planers		3.62	4.00	0.861
6. Relationship with clients	1-5	4.29	4.00	0.618
7. Relationship with qualified/certified demolition contractors	1-5	3.08	3.00	1.064
8. Relationship with Finance institutions	1-5	3.35	3.00	0.889
9. Relationship with government	1-5	4.19	4.00	0.811
Size of sample adopted: N=37				

As indicated by the mean values in Table 5.9, among the external relationships of AEC firms with other stakeholders, the relationship with clients is considered extremely well and the relationship with qualified/certified demolition contractors is seemingly relatively weak. The results indicate the qualified/certified demolition contractors are usually ignored at the design and construction stages of building projects. However, in order to improve the environmental performance of building projects, they should be consulted in the design stage first. Therefore, the AEC firms in Singapore should pay more attention to the relationship with qualified/certified demolition contractors in the future.

5.3.2. Reliability Assessment

Reliability has been defined as the “degree to which measures are free from error and therefore yield consistent results” (Peter, 1979). Using reliability analysis, the researcher can determine the extent to which the items in each factor are related to each other. This can provide an overall index of internal consistency of the factors, and also can help single out problematic items that should be excluded from the factor and/or included in another factor (Cao, 2006). According to Bagozzi (1980), there are four traditional methods used to estimate reliability: test-retest, split-halves,

alternative forms, and internal consistency. Since all the constructs in the study adopted multi-item scales, as Green (1988) suggested, the coefficient alpha should be used as a measurement of the internal consistency because the alpha measures the degree of co-variation that exists among the scale items. Therefore, reliability was operationalized as internal consistency, and was calculated using Cronbach's coefficient alpha in this study.

The Cronbach Alpha coefficient (α) has a value that ranges from 0 to 1. If the items making up the score are all identical and perfectly correlated, the $\alpha=1$; if the items are all independent, then $\alpha=0$. Therefore, the higher values indicate higher internal consistency of scales. It has been suggested that reliabilities of 0.50 and 0.60 should suffice (Churchill, 1979; Nunnally, 1978). Thus, 0.60 was set as the minimum acceptable value for this study. As discussed in Chapter 4, the conceptual model for this research incorporates three constructs: project management factors, organizational factors and firms' external relationships. Table 5.10 shows the Cronbach Alpha coefficients of the research factors of these constructs. From Table 5.10, it is observed that Cronbach's alpha of the factors are all above 0.6. This indicates that all the constructs in this study are internally consistent and can be used for further analysis. Details of the reliability analysis are given in Appendix D.

Table 5.10 Factors and Their Reliability

Factors	Number of items	Reliability (Cronbach Alpha)
Project Management Factors	19	0.90
Organizational Factors	12	0.73
Firms' External Relationships	9	0.82

5.4 Results Discussion

In the following sub-sections, the critical project management factors, organizational factors and firms' external relationships for delivering Green Mark certified projects

in Singapore are all identified using multiple regression analysis. The critical project management factors for delivering Green Mark certified projects in Singapore are explored in the first sub-section. Since the presence of inter-correlations between a large number of project management factors (independent variables) could affect the results of multiple regression analysis, factor analysis is applied first. Factor analysis can help extract a smaller number of underlying components as independent variables prior to conducting the multiple regression analysis. Furthermore, an in-depth discussion for the research findings is presented after regression analysis in each sub-section.

5.4.1. Critical Project Management Factors

Effective project management is very critical for the successful accomplishment of sophisticated projects (Hubbard, 1990; Chan, 2004). In the following parts, the critical management factors for delivering Green Mark certified projects in Singapore are identified. First, the factor analysis function in the Statistical Package for Social Sciences (SPSS) was conducted to select principal components for regression, since the presence of inter-correlations between a relatively large number of project management factors could affect the results of multiple regression analysis. After that, multiple stepwise regression was employed to explore the relative influence of the components extracted from factor analysis on environmental performance of building projects.

5.4.1.1. Factor Analysis

Factor analysis was used to identify underlying variables or factors that explain the pattern of correlations within a set of observed variables (Norusis, 2002). This technique reduces and regroups the factors identified, from a large number to a smaller and more critical one by factor scores of the responses.

(1) Evaluating the appropriateness of the factor model

Before factor analysis, the Bartlett test of sphericity and Kaiser-Meyer-Olkin test

(KMO) are required to determine the appropriateness of factor analysis for factor extraction. The Bartlett test of sphericity is a statistical test for the presence of correlations among the variables, while the Kaiser-Meyer-Olkin test (KMO) is a measure of sampling adequacy that compares the magnitudes of the partial correlation coefficients. When the Bartlett's test of sphericity is significant ($p < 0.05$), and the value of the KMO index is more than 0.5, the data set is suitable for factor analysis (Kaiser, 1974). In this research, the Bartlett's test of sphericity is significant ($p < 0.001$) (Table 5.11), and the value of the KMO index is 0.684 (above 0.5) (Table 5.11). The results confirm that the data are appropriate for factor analysis.

Table 5.11 Bartlett's Test for the Critical Project Management Factors and KMO

Bartlett's Test of Sphericity	Approx. Chi-Square	391.861
	df	171
	Sig.	.000
Kaiser-Meyer-Olkin Measure of Sampling Adequacy		.684

(2) Factor extraction

Factor analysis is then carried out to determine the underlying relationships among the proposed controllable project management factors and hopefully to reduce the large number of variables to a smaller set. It is conducted through a two-stage process: factor extraction followed by factor rotation (Norusis, 1993). The goal of factor extraction is to determine the factors through principal components analysis, whereas factor rotation is to make the factors more interpretable.

Table 5.12 Variances Explained by Critical Project Management Factors

Component	Eigenvalue	Percent of variance explained	Cumulative percent variance explained
1	7.434	39.126	39.126
2	2.584	13.602	52.728
3	1.468	7.727	60.455
4	1.239	6.521	66.976
5	1.087	5.722	72.698
6	.845	4.450	77.148

7	.688	3.622	80.770
8	.633	3.331	84.101
9	.532	2.797	86.899
10	.474	2.496	89.395
11	.412	2.170	91.564
12	.395	2.078	93.643
13	.333	1.755	95.398
14	.238	1.253	96.651
15	.216	1.135	97.786
16	.180	.945	98.731
17	.117	.616	99.347
18	.073	.387	99.733
19	.051	.267	100.000

Table 5.12 shows the eigenvalue for each factor. The eigenvalue is a measure of how standard variables contribute to the principal component (Teo *et al.*, 2005) and principal components are extracted based on the rule of “eigenvalues greater than one,” which suggests only the variables whose eigenvalues are greater than one should be retained (Lam *et al.*, 2008). Based on this rule, five components are extracted, and these components account for almost 73% of the total variance. The remaining 14 components altogether account for only 27% of the total variance. It indicates a model with these five components is considered adequate to represent the data.

(3) Factor Rotation

Principal components factor analysis with Varimax rotation conducted on the 19 controllable project management factors produces five underlying components. Table 5.13 shows the factor loadings of these controllable project management factors on these five components. The factor loading is the correlation coefficient between an original variable and an extracted component (Teo *et al.*, 2005). The larger the factor loading, the greater the factor contributes to the component. Usually, factors with loadings above value of 0.5 are considered significant in contributing to the interpretation of the component; otherwise, it is considered insignificant. As shown in Table 5.13, all factor loadings were greater than 0.5.

(4) Renaming factors affecting the environmental performance of building projects

For the sake of further discussion, it is necessary to rename the extracted five components based on the results of the analysis. The purpose is to better distinguish between the extracted components and controllable project management factors mentioned in previous sections. In summary, the five components were summarized as follows:

Component 1 consists of six factors: “commitment of all project participants”, “effective environmental compliance and auditing programs”, “adequate communication channels”, “project team motivation”, “effective feedback” and “strong/detailed plan effort in design and construction”. These factors all closely related to the management capability of human resource in the project organization. Therefore, this component can be termed “human resource-oriented factors”. This component accounts for the greatest variance (39.1%) among all the components.

Table 5.13 Factor Loadings of Critical Project Management Factors

Components	Code	Project management factors item	Factor loading
(1): Human resource-oriented factors	CSF6	Commitment of all project participants	0.794
	CSF12	Effective environmental compliance and auditing programs	0.767
	CSF11	Adequate communication channels	0.698
	CSF5	Project team motivation	0.686
	CSF13	Effective feedback	0.555
	CSF10	Strong/detailed plan effort in design and construction	0.530
(2): Technical and innovation-oriented factors	CSF16	Innovative management approaches	0.855
	CSF18	Innovative financing methods	0.792
	CSF15	Effective and efficient software development and application	0.790
	CSF14	Advanced machinery and equipment	0.653
	CSF17	Innovative technological approaches	0.645
(3): Support from designers and	CSF2	Skilled designers	0.728
	CSF19	Adequate financial budget	0.652

senior management	CSF7	Cooperation between architects and engineers	0.651
	CSF1	Support from senior management	0.648
(4): Project manager's competence	CSF4	Trouble-shooting	0.821
	CSF3	Skilled project managers	0.754
(5): Coordination of designers and contractors	CSF9	Contractors involved in design stages	0.840
	CSF8	Designers involved in construction stages	0.641

Component 2 includes five items: “innovative management approaches”, “innovative financing methods”, “effective and efficient software development and application”, “advanced machinery and equipment” and “innovative technological approaches”. These factors all emphasize on the technical level and innovative capability in project development. Hence, this component is termed “technical and innovation-oriented factors.”

Component 3 has four items: “skilled designers”, “adequate financial budget”, “cooperation between architects and engineers” and “support from senior management”. Designers mainly include architects and engineers in the design team. The “cooperation between architects and engineers” can help enhance the ability of designers so as to ensure that designers can provide more sustainable design plans for the Green Mark certified projects. The project organization can get different kinds of supports from senior management, including human resources, equipment as well as financial resources. Consequently, this component can be named “support from designers and senior management”.

Component 4 comprises two items, “trouble-shooting” and “skilled project managers”. “Skilled project managers” is associated with a project manager’s competence, and “trouble-shooting” ability for problems arising from construction sites requires the experience and problem solving skills of project managers. Therefore, this component is termed “project manager’s competence.”

Component 5 comprises two items, “designers involved in construction stages” and “contractors involved in design stages,” which are related to the coordination of participants between design and construction stages. Thus, this component is called “coordination of designers and contractors”. This component accounts for the least variance (5.7%) among all the factors from a statistical point of view.

The five extracted components represented the areas, which the participants of Green Mark certified projects deemed important. Although these components did not contain all the project management factors for Green Mark certified projects, they covered almost all the important factors.

5.4.1.2. Regression Analysis

In factor analysis, the controllable project management factors were grouped based on the level of correlation among them. However, factor analysis did not show which factor is most influential on Green Mark certified projects. Thus, regression analysis is conducted.

In the regression analysis, the five extracted components are the independent variables and the Green Mark level is the dependent variable. As the classical regression analysis assumes no linear relationship among independent variables (Chan, 2005), the scores of each underlying component (automatically generated by SPSS) can be considered as uncorrelated. This eliminates possible occurrences of multi-collinearity that may inflate the variance of the ordinary least-squares estimator. Hence, the estimated regression coefficients can be calculated with smaller mean square errors (Chan, 2005). A stepwise regression technique has been adopted to select variables using the SPSS REGRESSION program. The regression results are summarized in Table 5.14.

Table 5.14 Stepwise Multiple Regression Results of Project Management Factors and Green Mark

Independent variables	Beta Coefficient (β)	Sig.	F Value	R ²	Adjusted R ²
Component 5: Coordination of designers and contractors	-0.496	0.001	10.300****	0.384	0.347
Component 2: Technical and innovation-oriented factors	0.372	0.010			
Constant term: 3.194					
Size of sample adopted: N=37					
Note. ****P<0.001					

Table 5.14 shows the beta coefficient (β), coefficient of determination (R^2), adjusted R^2 , F-Value, and the significance level. As indicated, the model are significant at the level of $p < 0.001$. The components “human resource-oriented factors”, “support from designers and senior management” and “project manager’s competence” are excluded in this model, because they fail against the entrance criteria. Only the two components “coordination of designers and contractors” ($p \leq 0.001$) and “technical and innovation-oriented factors” ($p \leq 0.01$) are found highly significant. As R^2 of these two components is 0.384, 38.4% of variance in the successful implementation of Green Mark certified projects could be explained by these two components. The R^2 value is not too high and it is not surprising because only controllable project management factors are included in this model. Adjusted R^2 reflects the goodness of fit of the model, which is 0.347 in this model. Although it is not high, it is acceptable. In some the other researchers’ work (*e.g.* Kale, 1999; Park and Luo, 1998), they accept regression model even when most of the results of adjusted R^2 are below 0.3. Of these two components, “coordination of designers and contractors” has the higher absolute value of beta coefficient ($\beta = -0.496$), which means it is the most important factor as it has maximum influence in successful Green Mark certified projects.

It is noted that the regression analysis results do not mean that the other components obtained from the principle component factor analysis are insignificant. It only indicates “coordination of designers and contractors” and “technical and innovation-oriented factors” contribute more to the success of Green Mark certified projects in Singapore, especially “coordination of designers and contractors.”

5.4.1.3. Discussion of the Findings

Based on the results of the regression analysis, “coordination of designers and contractors” and “technical and innovation-oriented factors” are discussed in detail in the following paragraphs.

(1) Discussion on coordination of designers and contractors

As indicated by the regression findings in Table 5.14, “coordination of designers and contractors” is an important and evident factor, but inversely correlated to the successful implementation of Green Mark certified projects ($\beta=-0.496$). It implies that when “coordination of designers and contractors” is high, it is less likely to get Green Building Certificates. It is unexpected because usually coordination between designers and contractors can enhance the constructability and innovation aspects in design so as to improve the success level of Green Building projects (Zhu *et al.*, 2004; Pulaski *et al.*, 2006). The possible reasons may be that in Singapore 97.8% of the contractors are small–medium enterprises (SMEs) (Teo *et al.*, 2007). The level of innovation of these SMEs is relatively low because innovative design techniques could lead to inefficiencies in construction and costly ventures (Imada, 2002). When they are involved in the design process, they will tend to propose a way of construction that they are used to, instead of innovative environmental friendly construction technology and methods.

(2) Discussion on technical and innovation-oriented factors

The results in Table 5.14 indicate “technical and innovation-oriented factors” is positively correlated to the implementation of Green Mark certified projects ($\beta=0.372$). It means when “technical and innovation-oriented factors” is high, it is

more likely to get Green Building Certificates. It is not surprising because only by implementing environmentally friendly features can building projects meet rigorous environmental requirements required by Green Mark. Injecting these environmentally friendly features into projects requires “advanced machinery and equipment” and “effective and efficient software”. For example, electric machines can help reduce energy consumption and harmful gas generation; laser cutting machines and hydraulic piling equipment can help reduce noise pollution and harmful gas generation (Chen *et al.*, 2000). In addition, Green Mark certification places strong emphasis on energy efficiency and Building Energy Standard (BEST) is used for energy modeling features. Furthermore, Green Mark certification also emphasizes on innovative environmentally friendly features. Innovation accounts for 15% of the Green Mark grading. These innovative features include not only technological approaches, but also other financing methods and management approaches, such as lighting management system and environment management system.

5.4.2. Critical Organizational Factors

As we known, a construction firm may run several projects simultaneously and the way a construction firm manages can affect the performance of a project. Therefore, the important organizational performance for obtaining Green Mark certification will be identified and discussed below.

5.4.2.1. Regression Analysis

Stepwise regression technique is conducted with the organizational factors summarized in Chapter 4 as the independent variables and the Green Mark level as the dependent variable. The regression results are summarized in Table 5.15.

Table 5.15 shows the beta coefficient, coefficient of determination (R^2), adjusted R^2 , F-Value and the significance level. It can be seen from the Table 5.15, the model are significant at the level of $p < 0.001$. As indicated, “financial strength”, “training and education”, “qualified employees”, “incentives and compensation policies and

system”, and ”company image” fail to enter into the regression model. “Organizational culture”, “technical competency”, “R&D capability”, “organizational structure (centralization and formalization)”, “experience and knowledge in Green Building”, and “innovation capability” are found to be highly significant at the level of $p \leq 0.05$. R^2 is 0.933, which signifies that 93.3% of variance in the successful implementation of Green Mark certified projects can be explained by these factors. Adjusted R^2 reflects the goodness of fit of the model, which is 0.917 in this model. Since the beta coefficient ($\beta=0.350$) of “organizational culture” is higher than the beta coefficient of other organizational resources, and it can be concluded that “organizational culture” is more important in successful Green Mark certified projects.

Table 5.15 Stepwise Multiple Regression Results of Organizational Factors and Green Mark

Independent variables	Beta Coefficient (β)	Sig.	F Value	R ²	Adjusted R ²
Organizational culture	0.350	0.000	58.020****	0.933	0.917
R&D capability	0.260	0.000			
Organizational structure-Centralization	0.258	0.000			
Organizational structure-Formalization	0.251	0.000			
Experience and knowledge in Green Building	0.165	0.004			
Innovation capability	0.165	0.010			
Technical competency	0.164	0.012			
Constant term: -21.11					
Size of sample adopted: N=37					
Note. ****P<0.001					

5.4.2.2. Discussion of the Findings

The results in Table 5.15 revealed that six firm-specific resources and capabilities directly influenced the successful implementation of Green Mark certified projects. They are “organizational culture”, “technical competency”, “R&D capability”, “organizational structure”, “experience and knowledge in Green Building”, and “innovation capability”. The possible reasons are discussed as follows.

(1) Discussion on organizational culture

In the research findings of Table 5.15, organizational culture is one of important factors for Green Mark certified projects. Actually, culture is obviously a complex phenomenon. Although its influence on the project performance is ubiquitous (Cheah and Gurvin, 2004), the importance of organizational culture has been increasingly recognized. For example, a culture in quality management may help the firm achieve its quality goals by encouraging all employees, especially those at the project level, to change their attitudes, mindsets and skills to meet the quality requirements (Liu, 2007). The culture of innovation would encourage employees to participate in innovation (Liu, 2007) and the cultivation of safe culture in the organization can help improve the safe performance of projects it undertakes (Teo et al., 2005). In Singapore, some sustainable criteria were achieved by legislations such as pollution control and hazardous waste management. However, some criteria for example, minimization of the usage of non-renewable resources, natural resources and maximization of resources usage by recycling should depend on developing a culture of environmental protection of participates (Yeo, 2004). Logically, one would expect that incorporating a green culture in the members of the organization will encourage the employees to think “green” in their work routine to allow maximum incorporation of Green Building measures. For instance, in Banyan Tree, environmental considerations are always present in the company’s decision-making process to ensure full incorporation of sustainability in its projects (Khoo, 2002). Therefore, appropriate green culture, mainly including the impacts of design and construction activities and environmental

protection measures accordingly, should be cultivated for successful implementation of Green Mark certified projects.

(2) Discussion on R&D capability

The research findings show that R&D capability is one of important internal resources which can directly contribute to successful implementation of Green Mark certified projects. This finding was echoed by Yeo (2004), who also emphasized that the AEC firms should enhance R&D ability for attaining sustainable construction. The reason is that: Green Mark requires adoption of high-tech green technologies, for example, more accurate simulation software should be developed to help make decisions for energy saving. Furthermore, “sustainability requires innovations” (Yeo, 2004) especially for the certification of Green Mark, in which innovation accounts for 15 points out of 100. High R&D capability can help improve the technical level and innovation capability of AEC firms. However, in Singapore, the local construction firms have been unwilling to invest in research in development (Khoo, 2002). The reason could be that the tasks of architectural design and construction are usually assumed by different firms in Singapore (Pang, 1999). Moreover, the use of subcontracting practices may also inhibits research and development in the construction sector (Khoo, 2002). The compulsory requirements of Green Mark certification for new constructions can help create a conducive environment for R&D in AEC firms.

(3) Discussion on organization structure

Organization structure refers to a “pattern of relationships among positions in the organization and among members of the organization” (Egelhoff, 1979). More than three decades of research on organizations revealed that the structure of an organization is one of the most vital factors with potential to influence the performance of an organization and the performance of specific projects the organization undertake (Kale, 1999; Chen and Lee, 2007; Rowlinson and Cheung, 2008). Lin and Germain (2003) highlighted two main dimensions of organizational

structure: formalization and centralization. Formalization may be defined as the degree to which rules and procedures within a system are specified and/or adhered to (Ford and Slocum, 1976). Rules and procedures can be implicit as well as explicit, and can be used either to prescribe what should be done or what is forbidden (Sozen, 1985). Centralization refers to the extent of participation by organizational members in decision-making. In a centralized organization, final choices are made almost exclusively at high levels and unquestioning acceptance of top management decisions is expected. Such organizations are characterized with minimum level of participation from lower level members of the organization (Kang, 2006).

The results indicate centralization is preferred for Green Mark certified projects. It is unexpected because centralization usually inhibits innovation in the project team which is emphasized by Green Mark certification. The reason could be that: in Singapore, many construction operatives are unskilled foreign imports (Teo, 1999). You can not rely on their innovative ability to improve the environmental performance. Actually, it is the middle or senior managers in AEC firms who have extensive experience on Green Mark certified projects, and they are also much receptive to new ideas from countries like Australia, Canada and Japan who are currently very active in adopting green technologies (Teo, 1999). Guidance from the middle or senior managers and acceptance of top management decisions made by them should be encouraged. At the same time, formalized rules and procedures are formulated to standardize the management of Green Building process. The key practice is usually divided into two ways: planning and controlling. First, an overall plan for Green Building is usually provided as early as possible, for example, specific sustainable technologies and techniques, which should be incorporated to ensure specific level of Green Mark can be achieved, are usually set up in the design stage. Then, each of these technologies and techniques has to be closely measured and monitored to ensure the building is compliant with sustainability goals required by Green Mark. Furthermore, all these information about these Green Building measures should be well documented for certification application. Thus, effective organizational structure

(centralized and formalized) contributed to effective management of Green Mark certified projects.

(4) Discussion on experience and knowledge in Green Building

“There is a direct and positive relationship between project team members’ experience and project outcomes.” (Young and Samson, 2008). Firms can actually improve their project performance by selecting more knowledgeable and experienced team members (Pinto and Slevin, 1987; Pinto and Covin, 1989). In this regards, it can be expect that the experience and knowledge on Green Building projects are very important for improving environmental performance of building projects. Besides, Green Mark certified projects involve more complex design and construction processes, and too much documents are needed in order to get evaluation. Less experienced project team members, especially designers who are responsible for directly managing the Green Mark submission process, will have a harder time with compliance and documentation. Hence, experienced project team members, who have a good knowledge on the Green Building processes and a better understanding of credit and documentation requirements, are necessary to avoid unnecessary time delays and cost increase as concluded in this study. However, experience can be achieved only if the lessons learned from completed projects are kept in the organizational memory and used in future projects (Kululanga and McCaffer, 2001). Therefore, instead of choosing the AEC firms with the lowest bid, past experience and knowledge on Green Mark certified projects should be taken into account for the future new building projects. Since Green Mark is relatively new requirements in Singapore, only a few large AEC firms have undertaken Green Mark certified projects, and accumulated the necessary experience and knowledge. Most AEC firms, especially small and medium ones, should gain the experience and knowledge in the following three ways, in order to survive in the future Green Building market: recruiting experienced employees; cooperating with experienced firms; taking training courses provided by BCA.

(5) Discussion on innovation capability

Rangone (1999) defines “innovation capability” as a company’s ability to develop new products and processes and achieves superior technological and/or management performance. In this paper, the results found innovation capability of AEC firms is one of the essential factors for achieving Green Mark certification. The result is obvious because compared with other Green Building assessment systems, Green Mark especially encourages the incorporation of innovative solutions that is less polluting or more resource efficient, and the category of innovation takes up 15% of the total points available. Three items were identified as potential innovative solutions: innovative management approaches; innovative financing methods; innovative technological approaches. This result is consistent with Yang’s (2006) conclusion that innovations could bring about significant impact on improving the performance of buildings and promote the concept of sustainability in Singapore.

(6) Discussion on technical competency

Technical competency refers to the physical assets of a company such as machinery and equipment and the extent of technical know-how available that is necessary to undertake specific projects (Isik *et al.*, 2008). According to project management theory, fulfilling technological specifications is one of the major factors in the achievement of success in a project (Shenhar *et al.*, 1998; Raz, 2002). The regression results in Table 5.15 found technical competency of AEC firms plays an important role for successful implementation of Green Mark certified projects. It is reasonable because Green Mark requires high-tech green techniques. These techniques range from improvements in equipment and processes to the use of simple ways to control and reuse waste materials (Khoo, 2002). Technical support activities can help assure compliance with these requirements.

5.4.3. Critical Firms’ External Relationships

Although AEC firms are the main players in the design and construction stages of building projects, the improvement of environmental performance of building projects

also requires the participation of other players. The communication and collaboration between AEC firms and other stakeholders have been regarded as the firms' external resources. In the following parts, the critical external relationships of AEC firms for obtaining Green Mark certification will be explored.

5.4.3.1. Regression Analysis

In this part, multiple stepwise regression is used to identify the critical external relationships with the firms' external relationships summarized in Chapter 4 as independent variables and Green Mark as dependent variable. The regression results are listed in Table 5.16.

Table 5.16 Stepwise Multiple Regression Results of Firms' External Relationships and Green Mark

Independent variables	Beta Coefficient (β)	Sig.	F Value	R ²	Adjusted R ²
Relationship with clients	0.461	0.001	17.814****	0.690	0.651
Relationship with government	0.333	0.013			
Relationship with qualified/certified materials and products suppliers	0.267	0.014			
Relationship with good green consultants	0.247	0.043			
Constant term: 1.079					
Size of sample adopted: N=37					
Note. ****P<0.001					

As can be seen from the Table 5.16, the model are significant at the level of $p < 0.001$. Only four external relationships: "relationship with clients", "relationship with government", "relationship with qualified/certified materials and products suppliers" and "relationship with good green consultants" meet the entry requirements and are statistically significant at the level of $p \leq 0.05$. "Relationship with advanced equipment suppliers", "relationship with qualified/certified sub-contractors", "relationship with qualified/certified planers", "relationship with qualified/certified demolition

contractors”, and “relationship with finance institutions” don’t meet the entrance criteria and fail to enter into the regression model. As R^2 is 0.690, that signifies that 69% of the total variance could be explained by these four relationships. Of these four relationships, “relationship with clients” has a higher beta coefficient ($\beta=0.461$). It is can be inferred that “clients” plays the most important role for the Green Mark certified projects. Therefore, AEC firms should established good relationship with their “clients” in order to get Green Mark Certification for their building projects.

5.4.3.2. Discussion of the Findings

As show in Table 5.16, four external relationships, “relationship with clients”, “relationship with government”, “relationship with qualified/certified materials and products suppliers” and “relationship with good green consultants” have obviously influence for completing Green Mark certified projects. The possible explanations are explored as follows.

(1) Discussion on relationship with clients

Kamara (2000) defined a client as the person or firm responsible for commissioning and paying for the design and construction of a facility. They play a vital role in the successful outcome of a project (Lam, 2005). In this study, the clients is found to be the most important external stakeholder for the successful implementation of Green Mark certified project in Singapore. The professionals in the pilot study also emphasized the importance of the support from clients for the Green Mark certified projects. Because establishing good relationship with clients and communicating frequently with them could ensure the clients’ requirements are well outlined and presented to the project participants. This would enable the project participants to take appropriate decisions at the early stage of the project. Furthermore, implementation of innovative environmentally friendly features in buildings also needs support from clients. Besides, after awarded by Green Mark, buildings will be further assessed once every two years to ensure that buildings are continuously well maintained and managed. This also needs the support from the client. To sum up, clients can have an influence on Green Mark certified projects through the following five ways:

- (1) Clients can require AEC firms to pursuing higher Green Mark certification for their projects. Generally speaking, it is up to the client to decide what level of Green Mark certification to achieve. In Singapore, most of the projects are shown to target for the lower-ranked awards (Gold and certified). The reason may be that the higher rating requires a larger increase in upfront cost (Chu, 2008).
- (2) Clients can make use of procurement systems to influence Green Building. For example, clients can call for tenders with D&B. The D&B system can provide the conditions necessary to address the fragmentation of responsibility, which will promote sustainability.
- (3) The willingness of clients to commit themselves to more innovative and environmental friendly ideas is important in the move toward sustainable construction.
- (4) The construction industry in Singapore operates predominantly on the basis of subcontracting (Teo, 1999). The client can name or nominate some subcontractors with good track records of environmental protection to the main contractors.
- (5) Clients can adopt “the environment” as a fourth project objective in addition to the usually ones of time, quality and cost and consider environmental track records in the selection AEC firms. It can promote the development of environmental protection culture in AEC firms (Ofori *et al.*, 2000).

(2) Discussion on relationship with government

Besides clients, the government also plays an important role for successful implementation of Green Mark certified projects, as revealed in this study. In Singapore, the government has created a conducive environment for Green Building in the following ways:

- (1) Codes and regulations are effective measures as they lay down mandatory level of performance (Teo, 1999). To this end, environmental laws and environmental assessment systems have been designed and implemented in nearly every country. In Singapore, the environmental performance of building is assessed by Green Mark. Since 2008, Green Mark has become a compulsory requirement for new

buildings with Gross Floor Area (GFA) of more than 2000 m². This is the most important driving force in the implementation of Green Building.

- (2) Apart from adopting command-and-control regulations, the government can also provide financial incentives to encourage environmentally responsive operations. This is especially so since the implementation of Green Mark measures are costly (Chu, 2008). In Singapore, several financial assistance schemes have been developed to promote Green Mark certification. For example, Energy Efficient Mortgage (EEM) Programs, a type of mortgage that allows energy-efficiency features to be included in a mortgage loan, was adopted to improve the energy efficiency in homes (Tan, 2006). Furthermore, in order to encourage more developers to take the lead to strive for higher Green Mark ratings for their projects, BCA launched the BCA Green Mark Champion Award in 2008 and handed out free Gross Floor Area (GFA) for new private buildings.
- (3) In Singapore, the public clients contribute a lot to the total construction demand (Oo and Drew, 2005). The government can be seen as a major construction client and it can drive sustainable agenda by seeking for higher Green Mark ratings. Actually, the public sectors in Singapore have required all new, large air-conditioned public buildings to achieve the highest Platinum standard.
- (4) As Green Mark is a relatively new assessment system launched by BCA, the main difficulty for AEC firms is a lack of required knowledge on this assessment system and green technologies (Yang, 2006). In Singapore, different kinds of technical support have been provided by the government, for example, training courses on educating architects and other professionals on the subject of Green Building was provided by BCA. In addition, the Environmental Control Officer (ECO) scheme was launched. The ECO is responsible for the identification of potential or actual environmental health problems on the construction site and offers advises and recommends measures to the contractor on how best to solve with them (Ng, 2004).

In sum, we can conclude the government in Singapore makes great efforts to encourage Green Mark and reduce environmental effect caused by building industry.

(3) Discussion on relationship with qualified/certified materials and products suppliers

AEC firms transform the conceptual ideas of clients into “constructed reality” by using a wide range of resource inputs. Construction companies commonly procure these important resource inputs by forming exchange relationships with materials vendors (Kale, 1999). As indicated by the regression findings, relationship with qualified/certified materials and products suppliers plays a major role in influencing the implementation of Green Mark certified projects. It is easy to understand, because Green Mark certified projects require the use of high-tech components and sustainable materials which should be sourced from qualified/certified suppliers so as to ensure the materials meet environmental performance requirements. Furthermore, Green Mark places significant weight on innovation. Manufacturer and suppliers are key sources for construction innovation, because they often provide innovative components and building products that are incorporated into buildings (Anderson and Manseau, 1999). Hence, maintaining good relationships with qualified/certified materials and products suppliers can secure the procurement of building materials that meet the requirements of Green Mark. Moreover, sustainable materials and products generally cost more than their traditional counterparts. The good relationships with suppliers can also present some potential cost advantages. However, in Singapore, the market for sustainable products and materials is not fully developed. The suppliers who can supply sustainable materials and products are very rare. Therefore, the strong relationship with these certified suppliers is difficult to establish.

(4) Discussion on relationship with good green consultants

It was revealed from the regression results that good relationship between AEC firms and consultants with environmental track records could help complete Green Mark certified projects smoothly. The consultant is the professional which is generally hired by the owner to provide consultation during the project various phases (Munib, 2003). There are many reasons to hire consultants. According to Francks (1992), the first and most obvious reason is when a project team encounters a problem or task that the

current staff is not familiar or has direct experience with; in this case a consultant should be hired for their knowledge and technical expertise. Generally, Green Buildings involve more complex design and construction processes. Engaging professionals who are well trained can help to deliver green outcomes more efficiently (Chu, 2008). The involvement of green consultant is especially essential for projects pursuing Green Mark certification, because Green Mark emphasizes the adoptions of high-tech innovative components. Besides, Green Mark is relatively new assessment system in Singapore, and most of the AEC firms, especially small and medium ones, still lack adequate experience and expertise with the required green technologies. These experienced experts can help source sustainable materials, identify the potential environmental risks and provide recommendations for improvement. They can help evaluate all costs for innovative green measures and assist the project team in making cost-effective choices. Since they have a better understanding of credit and documentation requirements of Green Mark, they can also assist the project team managing the Green Mark submission process to ensure that no Green Mark points are lost due to carelessness. However, in Singapore, the green consultants are not widely involved in the design and construction stages. Architects and engineers are generally trained to act as the green specialist. The assessors from BCA, who are responsible for Green Mark assessment, may also help project team prepare documents for Green Mark application. On whole building projects, an architect or building engineer would have the advantages of being experts in certain areas of the building design and construction process. But acting as the Green Building consultant may take away from their ability to perform the day-to-day activities of their traditional professions. They may not be able to dedicate the time necessary and therefore struggle to effectively Green Building consulting along with their current role of architect or engineer (Harrigan, 2004). Therefore, AEC firms in Singapore should better establish good relationship with external good green consultant to make designing and building a Green Mark project much easier and less expensive.

5.5 Critical Success Factors (CSFs) Framework of AEC Firms for Green Mark Certified Projects

Based on the above statistical analysis of the empirical data from Green Mark certified project participates, a CSFs framework for Green Mark certified projects is developed as shown in Figure 5.1. This framework comprises of three classifications of factors. For the project management factors, “coordination of designers and contractors” and “technical and innovation-oriented factors” were found critical. Among organizational factors, “organizational culture”, “technical competency”, “R&D capability”, “organizational structure”, “experience and knowledge in Green Building” and “innovation capability” were found to be highly significant. “Relationship with clients”, “relationship with government”, “relationship with qualified/certified materials and products suppliers” and “relationship with good green consultants” were four most important external resources that the AEC firms should establish to efficiently pursuing higher Green Mark ratings.

Figure 5.1 CSFs Framework for the Success of Green Mark Certified Projects

5.6 Chapter Summery

To examine the application and guidance of the generic CSFs framework in real context practice, this chapter aims to investigate the relative importance of the factors in running Green Mark certified projects from the viewpoint of AEC firms in Singapore. By using factor analysis and multiple regression analysis of the empirical data from Green Mark certified project participates in Singapore, a CSFs framework for Green Mark certified projects is established. This framework can help AEC firms in Singapore achieve targeted green mark ratings more efficiently and effectively.

Chapter 6 Case Studies

6.1 Introduction

In Chapter 5 the empirical findings for the research were described. This chapter will investigate three cases and illustrate the findings from questionnaire survey. It reinforces the use of the Critical Success Factors (CSFs) Framework for AEC companies to achieve higher Green Mark ratings effectively and efficiently. This chapter is organized into seven sections. Section 6.1 gives a brief description of the content and structure of the chapter. Section 6.2 states the criteria for selecting the case study projects. Following that, three case studies are carried out in Section 6.3, Section 6.4 and Section 6.5 as illustrative examples for their relevance to the findings of the survey. Section 6.6 summarizes the main elements of the three case companies, and finally the conclusion is given in Section 6.7.

6.2 Selection of Case Projects

Multiple-case studies are adopted as they allow cross-case analysis and provide compelling evidence (Yan, 2006). Three main criteria were considered in selecting the samples of case projects for this research: 1) they are under the new construction category; 2) they are local non-industrial building projects in Singapore; 3) they are certified under one of the four categories of Green Mark certification (i.e., Platinum, Gold^{Plus}, Gold, Certified). In this study, a total of three projects are selected, namely Project A, Project B and Project C. Three organizations, Company A, Company B and Company C, were AEC enterprises who undertake either design work (for Company A and Company B) or construction work (for Company C). Variations in these three case study projects and organizations allowed for cross-case analysis, which enhanced the validity of the research results and provided insight for future in-depth research. The three case studies are briefly described in the succeeding sections.

6.3 Case Study One

The first case study project is named Project A. The company, responsible for the design work of this project, is named as Company A. In the following sections, relevant management factors in Project A and Company A will be described in detail.

6.3.1. Basic Information of Project A and Company A

This project was a new construction project with contracted sum of S\$18 million. This was an educational building with a floor area of about 21,000 m². It was initiated in 2008 and was completed by 2009. Client of this building was the Singapore government, who had extensive experience on Green Mark projects. Procurement method of this project was “general contracting” and contract type was “lump sum fixed price”, awarded through open competitive bidding. This project was certified with “Green Mark Gold”.

Company A was first established in Singapore in 1972. With the vast expertise and background of specialist skills from decades of experience, it is well placed to provide the best integrated design services. Company A recognized the need for sustainability and gained considerable knowledge on the energy and environmental impact from construction activities in many fields, including resources, waste and recycling, life cycle embodied energy, Green Building technologies and eco-profiling of construction materials. It established the sustainability goals of the project right from the beginning and formulated achievable strategies for implementation. It has committed to evolving and building a practice that provides innovative solutions to its client's developmental needs.

6.3.2. Management Factors for Project A

As indicated in Chapter 5, effective project management is very important for successful accomplishment of Green Mark certified projects. The performance of these management factors, as identified in Chapter 4, in Project A was described in the

following.

Coordination of designers and contractors

The architect, as a design team leader, was responsible for the overall administration of the design process. His main responsibility focused on coordinating the structure and service engineers in developing the drawings and specifications for the project. However, in this project, the architect also joined in the whole construction stage, to ensure all the construction work follow the design specifications so as to deliver a reliable service to the clients.

Technical and innovation-oriented factors

In this project, several types of innovative environmental friendly materials were used, such as recycled carpet, recycled concrete and pavement materials. Solar tube was used to bring in light from external into the first storey foyer space and water-saving sanitary wares was also used. Besides, CO₂ sensors were installed in the library and staff rooms. On the construction site, rotary bored piling machine were used, which could install piles with lesser noise and vibration. Energy simulation and management system were also applied to assess and control the energy consumption in this building project.

Human resource-oriented factors

As for supervision, the audit committee in this project, mainly including client's supervisors, project managers and Environmental Control Officer (ECO) was established. It could provide an early alert if design and construction activities were not complied with the requirements of Green Mark and clients. Furthermore, feedback mechanism was established, which targeted to better prepare documents for Green Mark and eliminate misunderstanding in communication. For effective documents feedback, email and regular meeting were the most important channels. However, without good communication, achieving Green Mark is impossible. This is especially true that this project is relatively large and complex, and adequate communication between project participants was required at the design and construction stages. In this

project, a variety of mediums, including mobile phone, email, regular meeting and workshop were used for effective communication.

Support from designers and senior management

The architect in this project was appointed by the clients. He has been involved in more than five Green Mark certified projects before and has extensive experience in this area. With the assistance of engineers, a good passive design with excellent natural ventilation and lighting was provided by the architect. For example, the depth of most classrooms is not more than 9.5 m to allow for natural day-lighting, which help the building lower capital and maintenance costs, and get the Green Mark points. Furthermore, top management support from the company also played an important role for the accomplishment of their work by providing sufficient resources, including staff, time, money and information.

Project manager's competence

In this project, a competent project manager with good communication skill and leadership ability was employed. He stayed on the construction site all day long and coordinated all the project participants to work together effectively. He was also good at finding out environmental pollution problems before accidents occurred. With his support, the environmental performance of this project was maximized with present resources.

6.3.3. Organizational Factors in Company A

As indicated in Chapter 5, the performance of AEC companies can also affect the performance of Green Mark certified projects they undertook. In this part, the performance of Company A in terms of the different aspects as identified in Chapter 4 was described.

Organizational culture

The interviewee in Company A said that green culture has become more and more important for the achievement of Green Mark certified projects in Singapore.

Company A utilizes all kinds of opportunities to improve the green culture in the company. As an example, employees are required to write on both sides of the page when using note-pads and reusing old file-folders for documents filing; turning off all lighting during lunch hour; as well as using recycled materials for all decoration during festival. It is believed the cultivation of green culture can enhance awareness of employees on environmental protection. Thus, all personnel in Company A would take advantage of every opportunity to improve environmental performance of every project. However, the interviewee added, “our company enhances the green culture not only for Green Mark but also for social responsibilities”.

R&D capability

The interviewee said, “R&D is a must to ensure that we are always at the forefront of construction events and activities, always at the tip of the sword. We have produced many R&D documents, journals, executive summaries and seminars from our combined efforts of consultancy and international networks”. With the wealth of databases that is built up from decades of experience and the international networks of such databases, Company A is in an excellent position to provide Green Mark certified projects to clients in Singapore.

Organizational structure

In Company A, the project managers take charge of the project management towards Green Mark under the direction of headquarter. It generally controlled the whole process of a project covering consulting, proposal, documents checking and inspection & test. At the same time, Company A established its own environmental performance control mechanism and reviewed project at a monthly meeting, which targeted to ensure the achievement of Green Mark as required by clients. Moreover, Company A had been achieving ISO 14000 certification since 2005, which ensures a standard environmental management for its service.

Experience and knowledge in Green Building

Company A began to pay attention to sustainability in construction in 1999, seven

years before the launch of Green Mark in 2005. During these years, Company A learned a lot about sustainable materials and advanced technologies from the overseas construction industry such as Europe, Korea and Japan and possessed lots of experience and knowledge in Green Building. Such experiences enabled Company A to get several Green Mark projects in 2006 and achieved Green Mark ratings successfully. Until now, Company A has been involved in more than ten Green Mark certified projects in Singapore. In addition, Company A also encouraged and supported their employees to attend Green Mark Manager & Green Mark Professionals (GMM & GMP) courses provided by Building & Construction Authority (BCA) and six managers were awarded as “Green Mark manager”. Thus, the interviewee emphasized “we can provide all kinds of service to the clients in the Green Building projects”.

Innovation capability

Company A established its own research center, which targeted to develop advanced construction technology, high quality environmental friendly building materials and efficient project delivery process. By developing its own techniques, materials, and methods, Company A enhanced its competitiveness to execute Green Mark certified projects in Singapore, which also help it to get numerous Green Mark projects from the clients. The interviewee said, “our experienced and talented staff always bring innovative solutions and added creative dimensions into the projects”.

Training and education programs on Green Building

Training and education programs on Green Building are very important agenda in Company A. Every employee in Company A has opportunities to attend the training courses of BCA. The company also kept sending its core technical and project managers to attend overseas conferences and seminars in this area, which provided good opportunities for them to communicate with experts in Green Building. Company A also created its own training and educational materials, which include environmental friendly materials and advanced technologies needed for Green Mark and are distributed to employees to improve their know-how.

Qualified employees on Green Building

The interviewee said, “human capital is the main reason we can complete Green Mark certified projects, since everything should be accomplished by our employees”. Until now, nearly every employee in this company has working experience on Green Mark certified projects. Among these excellent employees, more than six senior managers were awarded as “Green Mark manager” by BCA. These qualified employees can provide value-added consulting services to the clients and contribute to the continuous development of Company A.

Company image

In recent years, there has been an increasing focus on environmental performance in the construction market and more and more clients begin to emphasize environmental reputation in AEC companies selection. Company A tries to gain more experience and knowledge on Green Building and get all the awards required by the clients. The employees in Company A often attend conference and seminars and share their good experience with other experts. As quoted by the interviewee, “an established brand in environmental protection will create a good perception in our clients’ mind, which will help our company acquire more Green Mark projects in Singapore. Furthermore, the company’s good reputation on Green Building can help our company get more support from government thus more public projects as well”.

6.3.4.External Relationships of Company A

The relationships of AEC companies with other project stakeholders are generally regarded as the external resources of AEC companies, which could have an important influence on the environmental performance of their projects. The performance of the relationships between Company A and other stakeholders was described as follows.

Relationship with clients

The interviewee emphasized the most important thing for Company A is to establish a good relationship with clients. He said “our target is to provide products which should

meet the requirements of our clients and all our decisions regarding to the project, including the application of environmental friendly materials and technologies, should be approved by the clients first”. Therefore, without the support of clients, the achievement of Green Mark is impossible. The interviewee believes effective communication is the only way to ensure complete satisfaction of clients with the project, which comes with high environmental performance. In order to ensure good communication with clients for the achievement of Green Mark, Company A often provides training courses for clients on new environmental friendly technologies. In addition, Company A also organizes weekly meeting with clients’ on-site supervisors to report the progress of their projects, so that the clients can make timely suggestions on project status.

Relationship with government

The government in Singapore is working very hard to promote Green Mark in all efforts, including providing training courses to the AEC companies to help them know how to achieve Green Mark and improve the environmental performance of projects. The government is also responsible for the assessment of Green Mark at plan submission stage and audit environmental performance at construction stage. Therefore, establishing good relationship is important for achieving Green Mark effectively and efficiently. Furthermore, public projects contribute a large part to the total construction demand in Singapore. Continuously maintaining good relationship with government also helps Company A get more projects.

Relationship with qualified/certified materials and products suppliers

“The implementation of new environmental friendly materials and products is essential for the achievement of Green Mark. Therefore, knowing more about these kinds of information is important to enhance our service provided to our clients,” said the interviewee. In general, Company A can get the latest information in this regards through frequent communication with materials and products suppliers. Company A has one supplier-database and could get all the products they need effectively through the information on the database. Besides, Company A could get better discounts from

its supplier partners. Therefore, interactive external cooperation with suppliers would create win-win relationship.

Relationship with good green consultants

Company A established good relationship with some consultant companies who are famous for their Green mark consulting service. The interviewee said, “Green Mark consultant is usually appointed by the client, who is one of the most important participants for building projects pursuing Green Mark certification”. This is consistent with the conclusion derived from the pilot study. A good Green Mark consultant can propose many good green materials and technologies to the clients, architects, engineers and contractors. Frequent communication with Green Mark consultants can also help Company A obtain the latest information in the area of Green Building. Therefore, having good relationship with consultant companies is one of the important external resources for Company A.

6.4 Case Study Two

The second case study project is named Project B. The company, responsible for the design work of this project, is named as Company B. Relevant management factors in Project A and Company B will be described in detail in the following sections.

6.4.1. Basic Information of Project B and Company B

This was a new commercial construction building project with S\$500 million of contracted sum. The Gross floor area of this project was 60,000 m². This project was initiated by a private clients, with some experience in Green Mark certified projects. Procurement method of this project was “Design-Bid-Build” (DBB) and contracts type was “lump sum fixed price”. Bidding procedure for this project was selective bidding. This project was awarded “Green Mark Platinum”.

Company B, a leading international design practice, had 31 global offices all over the world and offers services in architecture, interior design, master planning, landscape,

urban design and building consultancy within Asia, the Middle East, Europe and the Americas. In Asia, Company B employed over 1,500 architects, urban planners, landscape designers and interior designers and was now the largest architectural practice in Hong Kong with further offices in Beijing, Shanghai, Chengdu, Shenyang, Macau, Singapore, Ho Chi Minh City, Hanoi, Delhi, Abu Dhabi, Dubai, Doha, Bahrain and Almaty. It was consistently strengthening and expanding its range of expertise across multiple sectors by dedicating to Research & Development and sustainability. Recently awarded “International Practice of the Year”, Company B has built its reputation on consistently being dynamic, talented, multi-disciplined and growing – in both expertise and stature.

6.4.2. Management Factors for Project B

As indicated in Chapter 5, the performance of project management plays an important role for the successful accomplishment of Green Mark certified projects. In this part, the performance of these management factors as identified in Chapter 4 in the Project B was described.

Coordination of designers and contractors

Since the procurement method for this project was Design-Bid-Building (DBB), the contractors joined in this project after the design stage. However, the designer organized a meeting and invited contractors, who are good at running Green Mark certified projects and plan to bid on this project, to attend and give their suggestions and advices. The interviewee in this project said that by getting contractors to join in the design stage as early as possible would have a positive effect on Green Mark, because experienced contractors could provide good advices and suggestions on green technologies and materials. Furthermore, the early joining of contractors could help them have a clear understanding of design intent and early detection of risk, especially for new materials and technologies. At the same time, in this project, the designer visited the construction site and discussed with the project managers frequently. It can enable designer to progressively introduce green concepts and ideas to contractors,

which will lower capital cost and maximize the environmental performance to achieve higher Green Mark ratings with present resources.

Technical and innovation-oriented factors

In this project, low-E glass and glass curtain walling systems were used, which can help lower Envelope Thermal Transfer Value (ETTV). Recycled concrete and pavement materials were also used. Besides, the application of the solar-tube daylight system and light weight roof garden system, further improved the environmental performance of this project. Since this project was located at central business tourist district with stringent environmental protection requirements, some advanced equipment, including hydraulic D-wall dragging machine and hydraulic vertical dragger, were used. Due to limited construction space for this project, remote breaker, which can work in confined space was used. Thus there was no need to excavate large working space, which also reduced protection work under ground. Being a landmark project, the contractor is able to get low interest loan from banks. Lighting and energy management system were also applied. Furthermore, new waste management system, pneumatic waste collection system, was employed in this project. In order to save space, cost and resources, this building shared carpark ramp with a neighboring building. All these aforementioned materials and technologies help this project score Green Mark points.

Human resource-oriented factors

All project participants had a high awareness of environment protection and adopted a proactive attitude to incorporate environmental considerations into their work. To be involved in constructing a landmark building in Singapore is itself an incentive for all the project participants from both the design and construction team. Any major environmental effects caused by the project might be reported in the Media, which would affect the reputation and image of their companies. To improve the environmental performance, they discussed in details to research into every possible areas to score Green Mark points and how to avoid possible risks when applied them. Besides, this project was closely monitored by the authorities and project team leaders.

As this project was located in the Central Business District, its dust levels and traffic conditions were the key auditing program during office hours. Several noise meters were installed on site and at surround residential properties to monitor night work noise levels at the site. In addition, the building under construction was directly above the MRT (Railway) station and across a canal, thus soil protection and earth movement monitoring were also important. The client and project manager also kept close track of the design and construction work to avoid possible environmental pollution risks. The progress of Green Mark related activities were reported on the weekly project consultant meeting. Besides the consultant meeting, different kinds of communication channels, such as mobile phone and personal interview, were applied by the project participants. However, routine reporting meeting was still the main and best effective communication channel.

Support from designers and senior management

The design team in this project had extensive experience on Green Mark certified projects and knew exactly how to score more Green Mark points effectively. For example, without the support of engineers, architects may select super clear glass for retail units at ground floor, resulted ETVV score below platinum standard. However, in this project, architects and engineers worked closely together to explore all possible high performance glass, which met the Green Mark requirement, yet did not unreasonably overrun budget. In addition, since this project is a landmark building, the clients agreed to go green wherever possible and provide adequate budget accordingly. The project team also got all the resources needed from their companies.

Project manager's competence

Project manager in this project had extensive experience on Green Mark certified projects and suggested many good ideas from his past projects to the design team for consideration. For example, the old hoarding installed during piling stage was supposed to be replaced. However, the project manager managed to convince the project team and client not to replace it but to refurbish instead, which helped save materials and improve environment performance. Besides, the project manager also

have high problem-solving ability and lead the project team achieve Green Mark effectively.

6.4.3. Organizational Factors in Company B

As indicated in Chapter 5, the performance of AEC companies can affect the performance of Green Mark certified projects they undertook. In this part, the performance of Company B in terms of different aspects as identified in Chapter 4 was presented.

Organizational culture

Company B always advocates Green/Environment sustainability and supports any effort to enhance organization culture on sustainability. Some environmental management booklets were provided for internal use and circulation. For example, Paper Security Policy, which includes encouraging staff to use re-cycled papers for printing draft documents as well as to print on both sides of the paper, was introduced in order to reduce, reuse and recycle paper usage in office. Besides, Company B often sends employees for Green Mark training courses so that they could advise their clients on sustainable measures. In summary, Company B has built up a culture of sustainability, instilling spirits of sustainability into the project work practices.

R&D capability

As one of the world's leading practices, Company B invests in research and leads cross-disciplinary initiatives to develop design methods through computation and parametric tools that help quantify, visualize and manipulate spatial, environmental and financial factors of a design. R&D Group in Company B focuses on three principle areas of research: Computational Design, Advanced Modelling and Sustainable Design. In addition, Company B also cooperates with some research institutions and universities for some innovative design solutions. For example, one carbon-management system was developed from the cooperation of Company B and other research institutions as a platform to benchmark and track project energy usage from design to operation. The interviewee in this company stated that more and more

budget was invested in R&D activities on green practices in the future which was driven mainly by the Green Mark certification. The Green Mark has emphasized the importance of R&D capability for the improvement of energy performance and innovation.

Organizational structure

Environmental performance is one of the Key Project Indicators (KPI) for all projects in Company B and its headquarter sets the environmental objectives and targets. Besides, its senior management also monitors the progress of each project through progress reporting at a monthly meeting. Project managers of each project are mainly responsible for the implementation on how to achieve the environmental performance target. At the same time, many project pollution control and environmental management procedures are formally documented, such as “Waste Management Handbook”, “Natural Resources Consumption Control” and “Green Mark Implementation Plan”. All these formal documentations facilitate the access of key procedural information, which help improve the environmental performance of projects, better prepare documents for certification application and also increase organizational management efficiency.

Experience and knowledge in Green Building

Company B, as a leading international design practice, offered sustainability services in architecture, interior design, urban design and building consultancy within Europe and the Americas about ten year ago. In Singapore, Company B has thus far been involved in more than 20 Green Mark certified projects. Hence it has extensive experience and knowledge on Green Building design solutions and technologies both at home and abroad. Company B often sends its employees to attend Green Mark Manager (GMM) and Green Mark Professional (GMP) courses provided by BCA and shares experience and knowledge with other companies. All these effort help Company B get all the necessary knowledge on how to achieve Green Mark at different levels effectively.

Innovation capability

Company B's commitment to sustainability and investment in research and development drives innovation in the practice's design-led approach. In Company B, each project is viewed as a collaborative opportunity for innovation and exploration of new ideas. Besides, Company B is also committed to recruit highly creative and innovative people, who may enhance the adoption of many innovative solutions in projects to help clients score higher Green Mark ratings. These innovative solutions mainly focus on product innovation, which can score points more readily and have higher "return on investment".

Technical ability

The current technical competency of Company B is sufficient and could provide all the necessary technical support for their projects to achieve the targeted Green Mark ratings. Attention for technical specification is mainly focused on materials and equipment specifications. Technical consultants are often invited to give presentations to employees on the special products used, which facilitates the application of new technologies and materials to score more Green Mark points. In addition, Company B also learn lots of knowledge on new sustainable materials, advanced technologies and design skills from other countries, such as Europe and American, which have vast experience on Green Building projects.

Training and education programs on Green Building

Company B pays attention to training and education of employees and provides a series of training programs for them, including training of new staff, short training courses, long term off-work training and overseas training. However, sending staff to attend Green Mark training courses in BCA is still the main and effective way to equip employees with necessary knowledge for Green Mark. In addition, Company B often provides platforms for communication between their employees and other professionals in this area. Furthermore, in order to learn more about advanced technologies and sustainable materials, Company B also sends employees to participate in the overseas Green Building projects or attend overseas conference,

seminars and sustainable building courses conducted by research institutions or universities, such as the university of Nottingham.

Qualified employees on Green Building

Company B is committed to recruit highly creative and innovative people from around the world. Most of their employees in Company B have been involved in more than one Green Mark certified projects. Many employees are certified as “Green Mark Manager” by BCA, who are qualified to provide professional advice and suggestions to clients and to help clients achieve the highest Green Mark rating effectively and efficiently. Since the extension of Green Building market in Singapore that comes with higher requirements of Green Mark, the company plans to recruit more experts in Green Building projects. These qualified employees could ensure the high satisfaction rate of clients and enhance the core competitive advantages of Company B in the Green Building market in Singapore.

Company image

Company B, as a world-class design practice, is reputable for Green Building projects in Singapore and all over the world. In Singapore, Company B tries to work with developers who want to pursue Green Mark projects, especially landmark or “Green Mark Platinum” projects and does their best to provide a thorough and efficient service to exceed the clients’ expectations. The interviewee of this company said, “our company has to establish a positive company reputation to enhance the competitive position in the new Green Building market, otherwise, we will have no business in five years later in Singapore”.

6.4.4. External Relationships of Company B

The relationships of AEC companies with other project stakeholders are generally regarded as the external resources of AEC companies, which could have an important influence on the environmental performance of their projects. The performance of the relationships between Company B and other stakeholders was described in the

following.

Relationship with clients

In Singapore, more and more clients tend to require Green Mark projects. However, not all of them have the necessary knowledge on the detailed environmental criteria of Green Mark. Often these criteria are too technical for them. Most project clients rely heavily on AEC companies for achievement of Green Mark. Company B pays attention to the relationship with clients. The interviewee said without trust and good relationship with their clients, achieving Green Mark is impossible for them. Company B often shares experience from past Green Mark projects with clients by conducting knowledge sharing seminars. Further, it is easier to communicate with clients with the “green” knowledge. The interviewee added that clients with extensive experience on Green Mark projects are more willing to commit themselves to innovative and environmental friendly ideas and even suggest their own green ideas to the project team.

Relationship with government

The relationship with government is also an important external relationship impacting the project outcomes. The interviewee said, “improving environmental performance of building projects is one thing, however, getting Green Mark certification is another thing”. In order to know more about the rules and procedures of Green Mark, Company B need to communicate frequently with the officers in BCA. Besides, Green Mark is often updated with the development of technology and social environment. Company B also need to update themselves by attending training courses offered by BCA. At last, the interviewee added, “our projects are generally supervised by Environmental Control Officer (ECO) and effective communication will ensure the projects achieve Green Mark ratings required by clients with limited resources”.

Relationship with qualified/certified materials and products suppliers

The ratings of Green Mark are assessed based on design decisions. Company B is

mainly in charge of design stage of projects, including the selection of sustainable materials and technologies. Although Company B has its own R&D department, most of the sustainable materials and technologies, applied in Green Mark projects are from suppliers. It also relied on suppliers to learn about the latest green components and building products. Therefore, establishing good relationship with them would help the projects of Company B achieve targeted Green Mark more effectively. Company B developed its own database of sustainable materials and suppliers, and established long-term partnering relationship with some of them.

Relationship with good green consultants

Company B also provides Green Mark consulting services for almost every step or decision of green projects. However, establishing good relationship with some consultant companies with excellent Green Mark consultants is still very important for Company B. This is because to achieve a Green Mark score of 90 and above is not an easy thing and sometimes they may need professional Green Building experts to give suggestions. Besides, good and innovative consultants know the current market costs and availability of green materials and they can also assist the project team in making cost-effective choices.

Relationship with qualified/certified sub-contractors

Generally, Company B was not bound contractually to its sub-contractors directly. However, the partnering agreement also called for it to work closely with the sub-contractors. Due to long-term cooperation with three of their sub-contractors in a number of successful Green Mark certified projects, Company B has established good relationship with them. These sub-contractors have a group of excellent employees and have a good track record in adapting to new environmental practices. They are committed to engage in environmental protection actions. Company B often recommended them to the clients and contractors in some of their Green Mark certified projects. It will enable the sub-contractors to participate in the project as early as possible and to attend any introductory training. Besides, these sub-contractors may also propose to Company B some useful suggestions for the

application of the latest environmental friendly materials and technologies. It can help the project team deliver Green Mark certified projects effectively and efficiently.

6.5 Case Study Three

Project C is the third case study project. Company C is responsible for the construction work of this project. In the following sections, relevant management factors in Project C and Company C will be described in detail.

6.5.1. Basic Information of Project C and Company C

This project was a new construction project with contracted sum of S\$296 million. The floor area of this project was about 80,823 m². It was a mixed development comprising of Hotel Block and Apartment Blocks. It was a joint venture project between three private clients, who have extensive experience on Green Mark certified projects. Procurement method of this project was “Design-Bid-Build” (DBB) and contracts type was “lump sum fixed price”, awarded through open competitive bidding. This project was certified with “Green Mark Gold^{Plus}”.

Company C was one of the leading building construction and civil engineering contractors in Singapore. It held the highest BCA grading of A1 for both general building and civil engineering which qualified it to undertake public sector construction projects with unlimited contract value. Company C was founded in 1959 in the provision of a complete supply chain of excavation, earth moving and trucking services. Over the years, Company C has developed core competencies in the fields of civil engineering and building construction and was able to warrant the timely delivery of various types of projects for both the private and public sectors. Besides successfully completing various design and build construction projects and acquiring the experience and expertise on foundation engineering, it can be also capable of taking on design and build projects which provided diversification to its businesses.

6.5.2. Management Factors for Project C

As indicated in Chapter 5, effective project management is very important for the successful accomplishment of Green Mark certified projects. In this part, the performance of these management factors as identified in Chapter 4 in the Project C was described.

Coordination of designers and contractors

In Project C, the architects and engineers often visited the construction site and communicated with project manager there. The architect progressively introduced green concept and ideas applied in this project to workers to allow them understanding of design requirements and to ensure what has been catered for in the design is effectively and efficiently incorporated. The architect also provided necessary information for the application of Green Mark.

Technical and innovation-oriented factors

In this project, road foundation and drains were made from recycled concrete. Besides, other new recycled materials, such as recycled ceiling boards and green paint were also used. A new self-cleaning cladding material, Ceramic Facade Cladding System, was applied resulting in lesser cleaning intervals, saving in labor and water consumption. In addition, condensate water recycling system was used which can resulted in water savings up to 19,300 m³ per year and the application of “WetSep” Silt Water Treatment System (total suspended particles of < 50mg/l) – can help save water of 3,210 m³ per month. Furthermore, lighting management system using easy-to-use color coded switches was used. Twin Chutes Pneumatic Refuse Collection System was also applied to encourage recycling and segregation of recyclable and non-recyclable wastes.

Human resource-oriented factors

To accomplish every activity effectively in this project, a series of objectives were proposed and the responsibilities of all employees were defined. All the objectives, including qualitative and quantitative ones, were reviewed at a weekly meeting. The

meeting helped to track individual tasks and ensure the successful implementation of every activity. The interviewee emphasized, “it is not just how you design, not just how the people say they are doing, it is more on how this whole process be supervised and being done in a correct way”. Therefore, client’s representatives communicated often with the design and construction team and regular green mark meetings were conducted, at least bi-weekly, to monitor the progress of all Green Mark related activities. Especially, the application of Green Mark related new materials and technologies were tightly supervised in the construction stage, since most laborers do not have related experience. Regular feedback was also provided by participants to project team leader during meetings on the progress of every Green Mark related activities. Besides regular meetings, email and phone were also the main communication channels in this projects, which ensure effective communication and team working.

Support from designers and senior management

The design team in this project had extensive experience on Green Mark certified projects and could incorporate green ideas as early as possible to score more points with limited resources. In the design team, architect generally design the aesthetic look of a building, while the engineers materialize it. In this project, architect and engineers cooperated closely, discussed in details to identify every possible areas to improve environmental performance and put them onto plan finally for approval by BCA. For example, architect and engineers worked closely together in the design of the green roof and rain water harvesting system. Excess rain water from the green roof (designed by architect) was channeled into rain water tank. Moisture sensors embedded into the soil and roof lawn (designed by engineer) indicated the need for irrigation on hot days and triggered the water pumps to pump water from the water tank to irrigate the roof lawn on a as need basis. Importantly, sustainable programs cannot run smoothly without top management support in allocating adequate resources. Clearly, full support from the organizations in this project help facilitate and implement green strategies for the successful completion of project.

Project manager's competence

An experienced project manager, who was in charge of the day-to-day management activities of the project, was appointed from within the organization. He monitored the construction activities tightly to ensure compliance with Site Construction Management and commissioning requirements in Green Mark. He also prepared accurate and complete documentation for the application of Green Mark.

6.5.3. Organizational Factors in Company C

As indicated in Chapter 5, the performance of AEC companies can also affect the environmental performance of projects they undertook. In this part, the performance of Company C in terms of different aspects as identified in Chapter 4 was described.

Organizational culture

Company C is committed to integrate environmental management system into all aspects of its business operations. For example, from developing a comprehensive Information Management System to reduce paper consumption while streamlining work processes (which won a BCA Best Practice Award in 2004), to using of more efficient and sustainable construction methods such as advanced formwork system, PERI formwork, which could be continually re-use thus reducing reliance on usage of traditional timber formwork. Its pursuit for excellence in creating a sustainable workplace is relentless. Besides, Company C also organized some workshops and seminars regularly to equip project managers with skills and knowledge on maximizing material recycling, minimizing wastage, increasing use of environmentally friendly materials, minimal adverse environmental impacts of their work as well as effective usage of resources. All personnel in Company C are requested to adopt “the environment” as a project objective.

R&D capability

Company C has its own R&D department. In the last three years, the R&D expenses amount to more than 1% of total revenue in Company C. Since facing dynamic and rapid changing nature of the new Green Building market, Company C will investment

more in research for enhancing its competitive advantage in the next few years, the interviewee reflected. Most of the R&D expenses in Company C will mainly concentrate on the development of new green materials and training and education of human resource.

Organizational structure

Environmental performance of projects was corporate indicator in Company C and specific environmental objectives and targets were all set by headquarter, such as the noise and dust level on construction site. The headquarter also monitored and controlled the environmental performance of their projects by periodical audit check to ensure they are delivered in the completed development. However, project managers were generally responsible for coordinating all the workers to improve the environmental performance to meet the requirements of the central organization and feedback the progress of projects. Besides centralization, formalization is also evident. Company C has been achieving ISO 14000 certification for its environmental management system since 2002. In addition, Company C also formulated rules and procedures to handle project environmental management, including waste management, natural resources consumption control and pollution control (noise, dust, air). The interviewee in Company C pointed out, more and more handbooks in this area will be developed to guide their members to adopt environmentally responsible practices. These handbooks will also introduce the preparation of documents for the application of Green Mark.

Experience and knowledge in Green Building

Company C has been involved in lots of Green Building projects in Singapore and gained extensive experience on Green Building projects, including the available measures and opportunities regarding green buildings and how to organize and manage the collaboration required of the many parties involved in the project. Furthermore, in order to better equip its staff with detail requirements of Green Mark, it also sends the employees to attend GMM & GMP courses provided by BCA. Therefore, Company C is not only experienced in green building processes but also

has a better understanding of credit and documentation requirements of Green Mark. It helps Company C ensure to cooperate effectively with other participants and provide clients with reliable projects.

Innovation capability

Company C has a long history of successful innovation and possesses higher innovative ability compared with other construction companies. The innovation activities of Company C mainly focused on more environmental friendly construction materials, new construction methods and techniques, such as recycled concrete and using waste products for bricks and wood chipboard. These innovation activities not only improve environmental performance of projects, but also reduce costs and speed up construction processes. In addition, the application of these innovative solutions also benefit Company C a lot financially, which encouraged the company to be more innovative in the future. For example, Company C once recommended one new anti-termite materials to one project team, which save the clients S\$ 20 million. The clients shared the savings with Company C and Company C was awarded S\$ 10 million. Until now, Company C has won various awards for innovations from Ministry of Manpower (MOM) in Singapore.

Technical ability

Company C developed a comprehensive Information Management System and often adopted more efficient and sustainable construction methods such as advanced formwork system and PERI formwork. It has also pioneered the use of mobile recycling system at construction sites in Singapore, recycling the water for other construction use while reducing the silt introduced into the drainage systems. This effort earned a BCA Best Practice Award in 2006 as well as recognition from Public Utilities Board (PUB) as a Friend of Water and achieving the Water Mark Award. The high level technical ability of Company C is allowing it to provide necessary building and construction processes which are more environmentally friendly. The interviewee stressed that with the increasing requirements regarding runoff control, dust and noise from construction, and many other environmental and health concerns, the technical

ability of Company C should be improved further in the future.

Financial strength

Company C has established good relationship with several financial institutions and banks. They can undertake more than 5 projects in Singapore simultaneously. However, the interviewee said that the Green Mark certified projects do not always require more financial budget. Although the application of new environmental friendly materials and technologies may incur higher initial cost, the extra cost will be paid by the developers. However, the interviewee added, in order to enhance the competitive advantages of Company C in the new Green Building market, more financial budget should be invested in R&D and recruiting higher qualified employees.

Company image

Company C is always associated with good quality and service in the construction market in Singapore. In recent years, with the increasing demand of Green Building and higher requirements of environmental performance on building projects, a good reputation on Green Building projects is very essential for acquire more market. Luckily, Company C has completed lots of Green Building projects and built up a good reputation in Singapore. It help Company C distinguish itself from those of their competitors and developed well in the new Green Mark market.

6.5.4. External Relationships of Company C

The relationships of AEC companies with other project stakeholders are generally regarded as the external resources of AEC companies, which could have an important influence on the environmental performance of their projects. In this part, the performance of the relationships between Company C and other stakeholders was described.

Relationship with clients

The relationship with clients had the power to directly influence not only the

company's performance, but also the project performance. The interviewee in Company C said that since most clients rely on project team to advise them for the achievement of Green Mark, building up mutual trust can facilitate the adoption of some green ideas. Besides, the interviewee also pointed out clients' involvement in getting all parties to provide pertinent and timely green information is essential for success of Green Mark projects. However, clients' participation in expediting communication flow is lacking in many projects. In addition, clients who exercise close involvement are usually satisfied with the final project quality. Therefore, encouraging them to join in the project team are important for the successful implementation of Green Mark certified projects. In order to develop open communication and effective coordination with client, regular meeting was often organized by Company C. Effective and timely communication with clients is the best way to establish and maintain good relationship with clients.

Relationship with government

The government in Singapore provided all kinds of effort to promote Green Mark projects, including technical assistance, financial assistance, education and training, design tools for Green Building, as well as laying down mandatory level of environmental performance. Besides, government in Singapore also took a leading role in driving sustainability agenda by requiring the minimum levels of environmental performance of public projects. The interviewee in Company C stressed, the good relationship with government is very important for the success of not only Green Mark certified projects, but also traditional building projects. Company C benefits a lot by the good relationship with government. The interviewee reflected that some of the existing environmental standard is outdated. For example, the maximum allowable noise level specified for night work already exceeded on site even there is no construction activity. It is up to the ECO whether they want to execute the punishment during inspection. Regular communication with government officers help ensure the smooth construction processes. Another example, one project of Company C is located at central business cum tourist district, the clients would like

to light up the building as much as possible as a landmark building. On the other hand, BCA as a green mark driver would discourage excessive external lighting on the building that consumes energy. Through good relationship between Company C and the government, waiver was obtained to install appropriate amount of lighting for festival season, but keeping the lighting consumption to the lowest during normal period and manage by special lighting management software.

Relationship with qualified/certified materials and products suppliers

Company C has established strategic alliance with some suppliers, which possess abilities to provide sustainable materials and technologies required by Green Mark. Although Company C has its own R&D department, most innovative materials and technologies applied in Green Mark projects are from suppliers. Some green materials are very rare and supplied by only a few suppliers. Thus it is important to establish good relationship with these suppliers for the procurement of green materials. For example, recycled concrete is an environmental friendly materials widely used in Green Mark projects. However, only one supplier in Singapore can provide this materials. In addition, these suppliers may ask for high price for sustainable materials if you did not have any relationship with them and have no latest information in this area. Similar example as the selection of façade clear glass in one past project, one supplier knew that the project team try to achieve platinum award but yet looking for super clear glass, they quoted for a very high price for the high performance low-e glass. Therefore, maintaining good relationship with material vendors also presents some potential cost advantages for Company C. In sum, the partnership with suppliers helps the Company to reduce risk, obtain cost advantages and enhance its technical know-how.

Relationship with good green consultants

Generally, clients can not be aware of the opportunities available for Green Mark projects and rely heavily on the pointed consultants to advise them. Company C, as contractor, should follow the requirements of consultants for resolve of Green Mark issues. Therefore, the interviewee stressed, effective communication with consultants

in very important for effectively and efficiently complete Green Mark projects. For most projects that Company C undertook, the green consultants often met and discussed with the construction managers at regular intervals (usually weekly) during the projects to identify the potential environmental risks on construction site and propose some solutions. It helped improve the environmental performance and ensure the compliance with site management protocol, construction waste management, erosion and sediment control, indoor air quality, and commissioning requirements. In the long-term cooperation with some consultant companies, Company C established partnerships with them. Maintaining good relationship with them help Company C learn a lot about green solutions and enhance technical and innovative ability, which facilitate to build a Green Mark building much easier and less expensive.

Relationship with qualified/certified sub-contractors

Company C established long-term relationship with some subcontractors and tended to rely on them for construction work in its projects, including Green Mark projects. With this process, part of the environmental responsibility of Company C was also transferred to their subcontractors. For example, subcontractors were often asked to work with unfamiliar or hard-to-obtain recycled-content materials and to document the costs they incur. In order to help the partner subcontractors improve their environmental performance and finish the construction work efficiently, Company C sometimes provided training courses and workshops to them. Besides, Company C often asked them join in the project as early as possible and attend the introductory training, if possible. By the long-term cooperation on Green Mark certified projects, these subcontractors cultivated high environmental responsibilities and possessed necessary experience and knowledge in this respect. They were more proactive in trying Green methods and also required less supervision. Besides, due to good relationship and mutual trust with their subcontractors, Company C sometimes may turned to their subcontractors for more capital when it encountered financial difficulties.

Relationship with finance institutions

Company C has formed good business relationship with the banks in order to enhance the companies' overall financial capability. The major source of acquiring financial resources of Company C is through bank loads. In addition to this, good quality relationship with other partners, especially the partners in the supply chain, such as material suppliers and subcontractors, present a feasible approach to get financial support. The good relationship with material suppliers and subcontractors helped Company C a lot when it face financial difficulties. However, the interviewee in Company C added, Green Mark certified projects would not cause too much extra financial burden to Company C, since the construction cost were commonly financed by the client with interim payments based on the progress of the construction process.

6.6 Summary of Case Studies

The three case studies in this research add value by providing a variety of instances of both the theoretical literature and the findings from survey. The case studies illustrate the link between management factors and the success of Green Mark certified projects. In terms of Green Mark certification achievement, the three case studies were all certified: one received Gold, one Platinum and, one Gold^{Plus} certifications.

6.6.1. Summary of Project Management Factors

Table 6.1 summarizes the performance of main project management factors of the three case projects. The significant factors according to its relevance to the success of Green Mark certified projects are summarized and explained in the following.

As indicated in Table 6.1, only Project B performed well in the factor of “contractors involved in design stages”. All the interviewees reflected that the contractors usually joined in the project after design was developed and Green Mark level was certified. The builders just built according to the design specifications and clients' requirements. Green Mark requirement was not specified in the builders' contract and their parts in contribution to Green Mark points was very minimal. Normally, there were also no

Table 6.1 Performance of Project management Factors in Case Projects

Project management Factors		Project A	Project B	Project C
Coordination of designers and contractors	Contractors involved in design stages	Normal	Good	Normal
	Designers involved in construction stages	Good	Good	Good
Technical and innovation-oriented factors	Innovative management approaches	Good	Very Good	Good
	Innovative financing methods	Normal	Good	Normal
	Effective and efficient software development and application	Good	Good	Good
	Advanced machinery and equipment	Good	Very Good	Good
	Innovative technological approaches	Good	Very Good	Good
Human resource-oriented factors	Commitment of all project participants	Normal	Very Good	Normal
	Effective environmental compliance and auditing programs	Good	Very Good	Good
	Adequate communication channels	Good	Good	Good
	Project team motivation	Normal	Good	Normal
	Effective feedback	Good	Good	Good
	Strong/detailed plan effort in design and construction	Normal	Good	Good
Support from designers and senior management	Skilled designers	Good	Very Good	Good
	Adequate financial budget	Normal	Very Good	Good
	Cooperation between architects and engineers	Good	Good	Good
	Support from senior management	Good	Good	Good
Project manager's competence	Trouble-shooting	Normal	Good	Normal
	Skilled project managers	Good	Very Good	Good

financial assistance and incentives to contractors. Therefore, most contractors were not willing to join in the design stage, which is not part of their work. Some contractors were even reluctant to use new sustainable materials and technologies, which may cause many potential risks on the construction site. However, the

interviewee in Project B said that the involvement of experienced contractors, especially some large-sized contractors from Korea and Japan, could propose some new materials and technologies to the design team and clients, which can be more green and reduce construction cost as well. More and more clients began to choose a main contractor at a very early stage in the design process and promised contractors to share with them the cost savings if new green and cheap materials and technologies were applied in the projects. It is found that although “contractors involved in design stages” may not influence the implementation of Green Mark certified projects at present, it is better to encourage contractors to provide their suggestions in the design stage if the client want to achieve higher sustainable performance in their projects. At the same time, the designers were actively involved in the construction stages in all three case projects, which indicate the importance of such factor for the achievement of Green Mark certified projects.

The interviewees in the three case projects all reflected that the success of Green Mark certified projects depend heavily on the application of new materials and technologies. For example, all three case projects paid attention to the application of recycled materials, such as recycled carpet, recycled concrete, recycled ceiling boards and green paint, which were used in every case project. Solar technologies and energy simulation software were also widely used in these projects. Besides, in order to reduce noise, vibration and dust pollution, some advanced equipments, such as rotary bored piling machine and hydraulic D-wall dragging machine were applied. In addition, pneumatic waste collection system was installed in both Project B and C. It was consistent with the comment of interviewee in Project B, who said this new waste management system was widely used in Green Mark certified projects in Singapore at present.

In the three case projects, all kinds of communication technologies, such as mobile phone, email, regular meeting and workshop, were used to enable effective communication and team work. Meanwhile, the design and construction work were

closely monitored by the client representatives and project team leaders through regular site visits and daily or weekly reporting meetings. In Project A, even an audit committee was established to supervise the daily work. Besides, timely reporting the status of projects to the corresponding authorities also helps ensure the successful implementation of every activity for the achievement of Green Mark. Therefore, it is concluded that effective environmental compliance and auditing programs, adequate communication channels, effective feedback can be regarded as the important management factors for the implementation of Green Mark certified projects.

All the interviewees said designers play the most important role for the achievement of Green Mark and document submission for the application of Green Mark. It is consistent with the conclusion conducted by Yang (2006) that the maximum number of points available for architectural development is 40, out of the total 100 points. In the three project instances, the designers all contributed a lot for the application of Green Mark. Meanwhile, architects and engineers communicated often to achieve the targeted Green Mark ratings. One interviewee reflected that the application of Green Mark needs huge amount of documents, which compels the close cooperation between architects and engineers. Besides, in all three cases, the project teams all received enough resources, including staff, time, money and information, from their companies to carry out day-to-day activities. It is concluded that the Green Mark certified projects can be effectively and efficiently accomplished with the support from experienced designers as well as senior management.

A project manager is effectively in charge of the project and has sufficient authority, personality, experience and reputation to ensure that everything that needs to be done for the benefit of the project is done. Effective project management will depend on the project manager's competency and authority (Jaselskis and Ashley 1991). All the projects managers in the three cases not only coordinated all the project participants to work together effectively to avoid environmental pollution. They also suggested many good ideas from their past projects for the design team to consider. Obviously, an

experienced project manager in Green Building can make designing and building a Green Mark project much easier and less expensive.

In general, the results of case studies in this chapter support that “coordination of designers and contractors” and “technical and innovation-oriented factors” indeed have the most maximum influence in successful Green Mark certified projects. However, “human resource-oriented factors”, “support from designers and senior management” and “project manager’s competence” also play a supporting role for the implementation of Green Mark projects effectively and efficiently, especially for the higher ratings Green Mark projects. From Table 6.1, it is found the higher ratings of the building projects, the more management factors should be given considerable attention by the project team. The project team in Project B, which pursues “Green Mark Platinum”, performed very well in every aspect. It is consistent with one interviewee’s feedback, “to achieve Green Mark score of 90 and above is not an easy thing, you should pay attention to every detail to ensure that no Green Mark points are lost due to carelessness”.

6.6.2. Summary of Organizational Factors of Case Companies

Table 6.2 summarizes the performance of organizational factors of the three case companies, architect companies for Company A and B and construction Company for Company C. Meaningful observations, drawn by gathering evidence from the case companies, are discussed in the following.

As indicated in Table 6.2, all three case companies emphasized the cultivation of Green/Environment sustainability and supported any effort to enhance organizational culture on sustainability. For example, in Company B, environmental management booklets were provided for internal use and circulation, and Company A encourages employees to bring their own mugs for refreshment to avoid disposable cups. Company C even organized some training courses for project managers on skills and knowledge of environmental protection. It is reasonable to presume that a green

culture can help AEC companies achieve its sustainable goals by encouraging all employees, especially at the project level, to change their attitudes, mindsets and skills to meet the Green Mark requirements.

Table 6.2 Performance of Organizational Factors in Case Companies

Organizational Factors	Company A	Company B	Company C
Organizational culture	Very Good	Very Good	Very Good
R&D capability	Good	Very Good	Good
Organizational structure	Formalization Centralization	Formalization Centralization	Formalization Centralization
Experience and knowledge in Green Building	Good	Very Good	Good
Innovation capability	Good	Very Good	Very Good
Technical ability	Normal	Very Good	Good
Financial strength	Normal	Normal	Good
Training and education programs on Green Building	Good	Very Good	Normal
Qualified employees on Green Building	Good	Very Good	Normal
Incentives and compensation policies and system on Green Building	Normal	Normal	Normal
Company image	Very Good	Very Good	Very Good

All three companies paid attention to the development of R&D capability. Under the increasingly competitive construction market, high R&D capability can ensure they are always at the forefront of construction events and activities. Obviously, it can also enable these companies to develop more innovation solutions on how to implement Green Mark certified projects and score more Green Mark points. Interviewee in Company B pointed out that R&D expenses has increased since the launch of Green Mark in Singapore and more budget will be invested in R&D on green practices in the future. This supports the conclusion that high R&D capability is needed in order to undertake Green Mark certified projects.

For the three cases, the project activities related to Green Mark performance were mainly monitored by their headquarters. However, the project team also possessed the

power to control the progress of these activities. At the same time, three companies have formulated rules and procedures to handle project management on Green Mark, which mainly include ISO 14000 Environmental Management System Handbook. Based on the experience of Green Mark certified projects, more and more handbooks in this area will be developed, which can facilitate the preparation of documents for the application of Green Mark, the interviewee in Company C added. It can be said that the organizational structure for this function appears to be more likely to be centralized and formalized in nature.

Looking at the case companies, it is found that they all have been involved in a lot of Green Mark certified projects and have extensive experience knowledge in this area. In general, they also send their employees to attend GMM & GMP courses provided by BCA to learn more on how to score more Green Mark points effectively. Besides, they are also very exposed internationally and pay attention to importing advanced and more green ideas and techniques from advanced countries. A good example would be Company B, an international company and beginning to provide green services ten years ago, which have extensive experience and knowledge on Green Building at home and abroad. The performance of the three companies in this factor supports the fact that experience and knowledge in Green Building would play a role in achieving Green Mark ratings.

All three case companies improve their innovative abilities by setting up a special research center, such as Company A, or recruiting highly creative and innovative people, such as Company B. Besides, by the application of innovative solutions construction companies also achieved lots of benefits, like Company C, which encourages construction company to be more innovative in the future. The interviewees in the cases companies reflected that the emphasis on innovative solutions of Green Mark push most AEC companies to improve their innovative ability, especially for architect and consultant companies. However, since more and more people began to realize the important role of construction team on improving the

environmental performance of projects, the innovation ability of contractors should also be enhanced.

As indicated in Table 6.2, both Company B and Company C possess good technical capabilities. The best performance in this factor is Company B because it is an international company and has been involved in many Green Building projects in overseas construction market before. This firm possesses lots of knowledge on new sustainable materials, advanced technologies and advanced design skills, and could provide all the necessary technical support for their projects to achieve the targeted Green Mark ratings.

Both Company A and B pay attention to training and education of employees. The main training programs for their employees on Green Mark projects are GMM & GMP courses provided by BCA. In addition, they all emphasize to equip their employees advanced technologies and sustainable materials from other advanced countries by sending them to attend overseas conferences and seminars and participate in the overseas Green Building projects. However, the training and education courses in this area in Company C is very rare. The possible reason may be that the achievement of Green Mark relies heavily on designers and consultants and not on contractors at present. The Green Mark requirement is also normally not specified in a construction contract. Thus no incentives are provided for contractors to participate in any training and education programs in this area.

The high quality of employees decides the core competitive advantage of AEC companies. Similarly, it is the high employees quality why some AEC companies can undertake and accomplish Green Mark certified projects. As shown in Table 6.2, both Company A and B have high quality employees and could provide clients with reliable buildings with required Green Mark ratings. They all have Green Mark certified managers in their companies. The interviewee in Company B said more and more experts in this area are needed. However, Company C, as a contractor, may not need so many skilled staff for running Green Mark certified projects. As the

interviewee in Company C pointed out that most of the contractors' work is to build according to the design specifications and provide what is required if the contract is awarded to them. But as the requirements of Green Mark and clients increase, it is believed, more and more experts on Green Building will be needed in construction companies as well.

There has been an increasing focus on sustainability in Singapore construction market as well as overseas construction market. Project clients largely rely on quality and sustainability reputation in AEC companies selection in competitive bidding, especially for some landmark projects, such as Project B. Since Project B was a landmark project and had higher environmental requirements, Company B, as a world-class design practice, which has a famous reputation on Green Building projects in Singapore and all over the world, was awarded the contract. Most AEC companies try to create a good brand not only in Singapore market, but also in the overseas market, so that they could distinguish themselves from those of their competitors and enter with relative ease into different market segments and various regions. Besides, the interviewees also reflected that it is the reputation of a company that influences stakeholders to provide or withhold support, which is consistent with Fombrun's (1996) conclusion.

Evidence drawn from the case companies confirm that "organizational culture", "technical competency", "R&D capability", "organizational structure (centralization and formalization)", "experience and knowledge in Green Building", and "innovation capability" are highly significant for the achievement of Green Mark. However, the case studies also indicate "training and education programs on Green Building", "qualified employees on Green Building" and "company image" support the implementation of Green Mark certified projects. Actually, these internal resources help AEC companies not only improve the environmental performance of their projects, but also enhance competitive advantages in the long-term and increase their market share.

6.6.3. Summary of External Relationships of Case Companies

The important external relationships of the three case companies are summarized in Table 6.3. The significant external resources for the achievement of Green Mark certified projects were explained in the following.

Table 6.3. Performance of External Relationships of Case Companies

External Relationships	Company A	Company B	Company C
Relationship with clients	Very Good	Very Good	Very Good
Relationship with government	Good	Good	Very Good
Relationship with qualified/certified materials and products suppliers	Good	Good	Good
Relationship with good green consultants	Good	Good	Good
Relationship with advanced equipment suppliers	Normal	Normal	Normal
relationship with qualified/certified sub-contractors	Normal	Good	Good
relationship with qualified/certified planners	Normal	Normal	Normal
relationship with qualified/certified demolition contractors	Normal	Normal	Normal
relationship with finance institutions	Normal	Normal	Good

All three companies were customer-orientated and established very good relationship with clients. Today the power of customers, who request and pay for the project, is much stronger than previously. The interviewees in the three companies reflected that all their decisions and suggestions regarding to the project, including the application of environmental friendly materials and technologies, should be approved by the clients first. For better communicating with their clients on green measures, they often provided workshops and seminars in this area and invited clients to join in. The case studies presented in this study clearly indicate the relationship with clients is the most important external resources of AEC companies and their support and commitment are fundamental for successful implementation of Green Mark certified projects. As well, the benefits of maintaining good relationship with clients are not confined to a

single project, but also for the company's long-term business profitability.

Besides having good relationship with private sector clients, all three case companies also built up good relationship with the local governments. The requirements of Green Mark was enacted by BCA in Singapore and BCA is also responsible for the assessment of Green Mark certified projects and auditing environmental performance at construction stage. In addition, BCA often updates the detailed requirements for the criteria in Green Mark with the development of technology and social environment. Therefore, without frequent communication with BCA, AEC companies will not know how to go for higher Green Mark ratings. The interviewee in Company C also pointed out the good relationship with government is very important for the success of not only Green Mark certified projects, but also traditional building projects. Furthermore, public projects in Singapore contribute a large part to the total construction demand in Singapore. Good relationship with government will help AEC companies get more public projects. The performance of the three companies mentioned supports the point that good relationship with government could help AEC companies implement Green Mark certified projects successfully and effectively.

All the interviewees in the three cases agreed that the application of new environmental friendly materials and products is essential for the achievement of Green Mark. Nearly every Green Mark certified projects, especially for higher ratings ones, applied many different kinds of new materials and technologies. These technologies and materials might not be the newest in the world, but it was totally new to building construction in Singapore. Although some companies may have their own R&D department, they heavily relied on suppliers to know these innovative green components and building products and they all established their own database about the suppliers. In addition, partnering with some suppliers could also help AEC companies get more discount on the products, so as to achieve low cost advantage in the construction market.

Green Mark consultants were generally appointed by the clients and almost every step

or decision relevant to the project was depend on the consultants. Establishing good relationship with Green Mark consultants will help facilitate effective and efficient cooperation between AEC companies and consultants. In addition, since Green Mark consultants normally have extensive experience and knowledge on Green Building projects in Singapore and international market, building good relationship with them could also help AEC companies learn more and improve technical ability in this area. Furthermore, good and innovative consultants know the current market costs and availability of green materials and they can assist the project team in making cost-effective choices to deliver reliable products to clients.

In the three companies, Companies B and C have long-term partner relationship with sub-contractors. Generally, the high qualified sub-contractors could make sustainable targets easy to manage because they are also committed themselves to environmental protection. The experienced ones may also have good suggestions and advices on how to score Green Mark points. They can deliver better quality of work to contractors with less supervision. In addition, Company C even turned to their subcontractors for more capital when it encountered financial difficulties. In sum, maintaining good relationship and building up mutual trust with subcontractors, AEC companies are more likely to successfully completed not only Green Mark certified projects, but also traditional projects.

It can be seen that all three case companies had built up good relationships with clients, government, qualified/certified materials and products suppliers and good green consultants that support the findings of the questionnaire survey in Chapter 5. However, since most construction work rely on the sub-contractors in Singapore, the relationship with qualified ones also help enhance the overall performance of building projects, including environmental performance. In sum, high levels of collaboration between the aforementioned parties can provide faster response to clients' needs and make their clients more satisfied. It could result in a "win-win" situation and improve the project environmental performance effectively and efficiently.

6.7 Conclusion

In this chapter, three case studies were conducted and observations drawn from the case studies were presented. These case studies revealed what key management factors these case projects and companies emphasized on to improve their project environmental performances. The results were compatible to the findings of the questionnaire survey in Chapter 5 and validated the CSFs framework. Besides, several other management factors, which are more likely to support the implementation of Green Mark certified projects, were also identified. In addition, the case studies provide an in-depth look into why and how these projects and companies improved these factors. Next, Chapter 7 will present the conclusions that are summarized as a result of the research.

Chapter 7 Conclusions

7.1 Review of Research Work and Conclusions

As identified in Chapter 1, the primary objective of this research was to develop generic conceptual model to help AEC firms undertake Green Building projects successfully and effectively. The generic conceptual model should identify all the critical activities (including technical and managerial activities) of AEC firms for improving environmental performance of their building projects. Besides, since little work has been done on managerial activities, a generic framework which can mainly link the critical management factors to the environmental performance of building projects should be established. The ultimate goal is to provide designers and contractors with valuable information on how to achieve excellent environmental performance in their Green Building projects.

These objectives are too complex and a large number of variables can have a potential influence on the environmental performance of building projects. In order to identify these variables systematically and comprehensively, simple theoretical frameworks, Porter's value chain and system models, were extended applied to Green Building projects. Based on the analysis of value chain and system frameworks for Green Building projects, the generic conceptual models of AEC firms and CSFs framework to deliver Green Building projects were established. The general conclusions made from the research have provided valuable insights into existing knowledge and were summarized as follows.

(1) Generic Revolution Model of AEC firms towards Green Building projects

Since the concept of Green Building is relatively new and intangible, how to incorporate the principles of sustainable development in the building projects remains vague among project participates. In this study, a Generic Revolution Model of AEC firms towards Green Building is established. This model suggests that generally five

main criteria were used to assess the environmental performance of building project: energy, water, materials, indoor environment and outside environment (soil erosion, dust, harmful gases, noise, liquid effluents) in the design and construction stages. Four types of activities that should be paid more attention in order to improve the environmental performance of building projects. Firstly, Green Building measures in the design and construction stages, such as solar panel and green roof should be applied. Besides the adoption of high-tech technical measures, project management activities (e.g. adequate communication channels) and organizational activities (e.g. regular training and education programs) also support the successful achievement of Green Building. Finally, the support from external stakeholders, such as clients and government, also plays an essential role for delivering Green Building projects. Based on this model, the AEC firms will understand how to deliver green building projects clearly and holistically.

(2) Generic Critical Success Factors (CSFs) Framework of AEC Firms towards Green Building projects

At present, most of the researches for Green Building projects strongly focus on high-tech Green Building measures, little work has been done to investigate management activities for Green Building projects. In this study, a generic CSFs framework mainly exploring the management activities of AEC firms towards Green Building projects was developed. There are a large number of management factors affecting the implementation of Green Building and most of them listed in this framework exist and are embedded in every project. However, the influence of each of these factors would differ in various countries owing to external factors, for example, different assessment indicators may be used in different countries and the socio-cultural environment may be different among these countries. This framework can serve as a guide to identify critical management activities that are needed and suitable in a specific region. However, it would be difficult, if not impossible, to compare the relative significance of these factors at different levels of focus. Therefore, in this framework, these factors have been grouped into three

classifications: project management factors, organizational factors and external relationships. The detail factors in each of the three groups were listed in Figure 4.9 in Chapter 4. Meaningful comparisons can be made among the factors at the same classification so as to identify the critical factors for one specific Green Building rating system in a country.

(3) Critical Success Factors (CSFs) Framework of AEC firms for Green Mark Certified Projects

In order to examine how this proposed generic CSFs framework can be successfully applied in a specific context, a specific CSFs framework, which can help AEC firms undertake Green Mark certified projects in Singapore, was created. For the establishment of this CSFs framework, factor analysis and stepwise multiple regression analysis were applied to analyze the empirical data from Green Mark certified project participants. All the critical factors for Green Mark projects and the beta coefficients of these critical factors are summarized in Table 7.1.

Generally, if a factor has higher beta coefficient, such factor is considered much more important than the other factors in this classification. As shown from the Table 7.1, “coordination of designers and contractors” is more important than “technical and innovation-oriented factors”. It is unexpected that the “coordination of designers and contractors” has a high negative impact on Green Mark certified projects. At present, the contractors indeed do not have close communication with designers in a project in Singapore and it may help the projects get Green Mark certification. However, the technical and innovative level of building projects in Singapore is relative low as compared with other western countries. More research work should be conducted in this area. Among organizational factors, “organizational culture”, “R&D capability”, “organizational structure”, “experience and knowledge in Green Building”, “innovation capability” and “technical competency” are found to be significant in descending order. Although “organizational culture” is the most important factor, changing an organizational structure takes much less time than changing organization

culture (Rowlinson and Cheung, 2008). Therefore, most AEC firms could change the structure of their firms so as to help their projects achieve Green Mark certification timely. “Relationship with clients” is the most important relationship AEC firms should establish for achieving higher Green Mark rating, while “relationship with good green consultants” is not found so important as compared with other relationships. In the context of Singapore Green Building industry, the important roles of clients and government have been emphasized all along, especially the participation of clients in the early decision-making process of Green Mark certified projects. However, in order to improve the environmental performance of building projects effectively and efficiently, the relationships with qualified/certified materials and products suppliers, and good green consultants should also be paid enough attentions.

Table 7.1 Beta Coefficients of CSFs for Green Mark Certified Projects

Critical Success Factors		Beta Coefficient (β)
Project Management Factors	Coordination of designers and contractors	-0.496
	Technical and innovation-oriented factors	0.372
Organizational Factors	Organizational culture	0.350
	R&D capability	0.260
	Organizational structure	0.258
	Centralization	0.251
	Organizational structure Formalization	0.251
	Experience and knowledge in Green Building	0.165
	Innovation capability	0.165
	Technical competency	0.164
External Relationships	Relationship with clients	0.461
	Relationship with government	0.333
	Relationship with qualified/certified materials and products suppliers	0.267
	Relationship with good green consultants	0.247

Besides, quantitative analysis mentioned in Chapter 5, three qualitative case studies were conducted in Chapter 6. The results of case studies, not only validated the CSFs framework for Green Mark certified projects developed in Chapter 5, but also provided an-depth understanding on why these factors important and how to improve the project and organization performance in these aspects. In addition, the case studies also illustrated that the generic CSFs framework can be easily adapted to a specific situation to facilitate the exploration of needed CSFs for one specific Green Building assessment system. These conclusions could assist AEC firms to have a holistic understanding of how to get their project being certified by Green Mark efficiently and help them to avoid failure in the future.

7.2 Contributions of the Research

The current research effort emphasizes four specific contributions: firstly, a Generic Revolution Model of AEC firms towards Green Building projects is established. Base on this model the participants from AEC firms will know clearly and holistically what activities they should do for Green Building projects. Secondly, the value chain and system frameworks for Green Building, which is an extend application of Porter's value chain and system models, are introduced. This is the first time to integrate the value chain and system frameworks into Green Building projects. This integration can serve as an innovative way to help explore the important potential management factors within the control of AEC firms for delivering Green Building projects systematically and comprehensively. Additionally, it can also be used as a new way to assist recognizing elements for other specific aspects of project performance in the building industry, such as cost, time and quality. Thirdly, previous studies mainly focus on technical solutions instead of management methodology for Green Building projects. In this study, a general CSFs framework for improving environmental performance of building projects is developed. It can provide participants from AEC firms with a focus for what they should be aware of in order to adopt Green Building measures effectively and maximize the sustainability of the built environment. This model also serves as guide to further explore critical management factors that are

needed for specific Green Building rating system in different regions. Fourthly, a specific CSFs framework of AEC firms, which can help get the building to be certified by Green Mark in Singapore, is created. This is the first comprehensive empirical research study which provides valuable insights into the critical management factors of AEC firms for Green Mark. It would allow project team members and corporate management team members to concentrate on the more important variables and manage them well, thereby implementing successful Green Mark certified building projects effectively and efficiently in the future.

7.3 Research Limitations

Although lots of conclusions and findings have been presented in this study, there are several limitations: firstly, due to time constraints, only 37 samples are obtained for this study. Although the sample size of the responses is large enough to verify the proposed framework statistically, more data are needed to have better results. Secondly, as we all known, in order to improve the environmental performance of building projects, all the players in the life cycle of building projects, for example, construction-related manufacturers or suppliers, planners and demolition contractors should work together. However, the frameworks in this study are established mainly from the perspective of AEC firms only covering design and construction stages. Thirdly, the research primarily focuses on new building construction. Even though there are Green Building rating systems for building renovation and demolition, they are not considered in this study. Fourthly, industrial building construction, which is also a main part of construction industry and major source of environmental pollution, is beyond the scope of this study. Only residential, commercial and office buildings are considered in this research work. Fifthly, there are a large number of factors having potential effects on running a Green Building project successfully, such as the size of the building projects and the weather conditions. However, only the management factors within the control of AEC firms are considered in this research. Finally, in this study, all the Green Building projects samples are the Green Mark projects in Singapore due to the constraint of time. More and more building projects

samples certified by other Green Building assessments systems in different regions should be collected for verifying the application of the generic CSFs framework.

7.4 Recommendations for Future Research

Possible future research work is recommended particular as follows:

- ◆ This study is limited to the design and construction stages of Green Building projects. Generally, different factors are considered critical in different phases of a project. The Critical Success Factors (CSFs) for Green Building projects over the whole life cycle should be studied in the future.
- ◆ The samples collected in this study focused on the Green Mark projects in Singapore. It is recommended that the generic CSFs framework developed in this study could be applied to Green Building projects certified by other assessment systems in other countries, such as LEED in the United States, or BREEAM in UK. This will help establish a strong body of empirical knowledge related to the CSFs for Green Building projects for different assessment systems in different countries for comparison.
- ◆ This study only explored the CSFs for environmental performance of building projects. However, a successful building project is usually evaluated on cost, time and quality performance. The CSFs for cost, time and quality should also be identified in the future research work, and the comparison of CSFs for different aspects of building performance can facilitate the integration of management components for better building performance.
- ◆ Until now, no research work has been done to study the impacts of Green Building on the strategic performance and overall performance of AEC firms. This perspective is likely to be a critical driving force for the market growth of Green Buildings. The identification of CSFs for Green Building in this study could help explore the relationship between Green Building, competitive strategy and firms' performance. An in-depth study to correlate CSFs for Green Building with strategic direction and firms' performance should be conducted in the future studies.

7.5 Chapter Summary

The research work met the objectives set out in Chapter 1, and the main conclusions and the value of the research were summarized. Furthermore, the limitations of the research work were presented and future research directions were suggested. It is believed that the current research provides insights on the knowledge of the development of Green Building projects and also provides practical benefits to project participants.

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APPENDICES

Appendix A: Questionnaire

Appendix B: Reliability Analysis

**Survey on Critical Success Factors (CSFs)
of Architecture, Engineering and
Construction (AEC) Organizations towards
Green Building**

School of Civil & Environmental engineering

Nanyang Technological University

Dear Sir/Madam:

Green building has enjoyed rapid development in recent years, and it will be a huge potential market in the near future. AEC organizations, which play an important role in promoting construction industry growth, are facing with challenges on how to incorporate sustainability into their projects. **The objective of the research project at School of Civil & Environmental engineering, Nanyang Technological University (Singapore), is to identify the Critical Success Factors (CSFs) of AEC firms towards green building projects.**

If you were involved in a Green building project (building with Green Mark certified) before, your contribution to our survey is of great importance to our research. It will take about 25 minutes to complete this questionnaire. Please answer all the questions and kindly tick in the appropriate box. We assure you that your responses will be kept confidential and will be used only for the purpose of academic research. In appreciation for your assistance, we will share with you the findings of our study once we complete it. If you have any queries about this study, please do not hesitate to contact me.

Thank you very much for your time and cooperation. We wish you every success in your business.

Sincerely

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..... **Feedback**

☐ I want the findings of the questionnaire survey

Name:

Company:

Tel No:

Fax:

Email:

Part I: Background information about the respondents

1. What is your designation?

- ☐ President
 ☐ Director
 ☐ General Manager
 ☐ Project Manager
☐ Department Manager
 ☐ Engineer
 ☐ Architect
 ☐
 Contractor/Builder
☐ Others, please state: _____

2. Years of experience in building industry: _____ years

3. Number of green building projects you have been involved in:

- ☐ 1 project
 ☐ 2 projects
 ☐ 3 projects
 ☐ > 3 projects, (please state)

Part II: Background information about the respondents' firm

1. Organization's name in which you are working in: _____

2. Total number of full-time employees in your company: _____

3. Is your firm certified with environmental management systems such as the ISO 14000 series?

- ☐ Yes
 ☐ No

4. Organizational structure – formalization

Please choose one or more items listed below for which your company has established formalized procedures, rules, or regulations, and tick the appropriate box in the tables

Project management	☐	Responsibility of the department	☐
Quality management	☐	Human resource management	☐
Contract management	☐	Financial management	☐
Cost management	☐	Marketing management	☐
Technology management	☐	Others, if any,	☐

5. Organizational structure-centralization

Please choose one or more decision-making items listed below which are controlled by the headquarter, and tick the appropriate box in the tables

Bidding decision	☐	Selection of technological scheme	☐
Material procurement	☐	Project cost control	☐
Setting of contractual terms	☐	Capital budget control	☐
Subcontractor selection	☐	Allocation of manpower	☐
Structure of project team	☐	Others, if any,	☐

6. Organizational culture

Please choose one or more items listed below which represent an influential theme in your company culture, and tick the appropriate box in the tables

Emphasis on project quality	☐	Customer satisfaction	☐
Emphasis on project environmental impacts and protection	☐	Pursuing innovation	☐
Emphasis on human development of capital	☐	Organizational learning	☐
Emphasis on cooperation of employees	☐	Others, if any,	☐
Emphasis reputation and brand name	☐		

Please rate your company in terms of the following variables, compared with your major competitors, and tick the appropriate box in the tables.	Poor=1 Normal=3 Excellent=5				
	1	2	3	4	5
1. Financial strength	☐	☐	☐	☐	☐
2. Technical competency	☐	☐	☐	☐	☐
3. Experience and knowledge in green building	☐	☐	☐	☐	☐
4. Training and Education	☐	☐	☐	☐	☐
5. Qualified employees	☐	☐	☐	☐	☐
6. Incentives and compensation policies and systems	☐	☐	☐	☐	☐
7. Company image	☐	☐	☐	☐	☐
8. R&D capability	☐	☐	☐	☐	☐
9. Innovation capability	☐	☐	☐	☐	☐
10. Others, please state:	☐	☐	☐	☐	☐

Please describe your company's relationship with the following key parties .	Poor=1 Normal=3 Excellent=5				
	1	2	3	4	5
1. Qualified/certified materials and products suppliers	☐	☐	☐	☐	☐
2. Advanced equipment suppliers	☐	☐	☐	☐	☐
3. Qualified/certified sub-contractors	☐	☐	☐	☐	☐
4. Good green consultants	☐	☐	☐	☐	☐
5. Qualified/certified planners	☐	☐	☐	☐	☐
6. Clients	☐	☐	☐	☐	☐
7. Qualified/certified demolition contractors	☐	☐	☐	☐	☐
8. Finance institutions	☐	☐	☐	☐	☐
9. Government	☐	☐	☐	☐	☐
10. Others, please state:	☐	☐	☐	☐	☐

Part III: Green building projects information

Please select one **completed green building project (preferably Building Projects in Singapore)** that you had been involved and provide details by answering the following questions. This information will be kept anonymous and will only be used for this research.

Project information

1. Name of project: _____
2. Nature of project:

☐ New construction ☐ Renovation ☐ Others, please state: _____
3. Which kind of building type:

☐ Commercial ☐ Residential ☐ Office ☐ Educational ☐ Industrial
☐ Others, please state: _____
4. If it is Green Mark certified, what is the level:

☐ Certified ☐ Gold ☐ Gold^{Plus} ☐ Platinum
5. Type of client:

☐ Public sector ☐ Private sector ☐ Other, please state: _____

Project procedures

1. Bidding procedure for the project:

- ☐ Open competitive bidding ☐ Selective bidding/prequalification ☐ Negotiation
☐ Other, please state: _____

2. Procurement method

- ☐ Design-bid-build ☐ Design-build ☐ Build-operate-transfer ☐ Management contracting

- ☐ Develop & Construct ☐ General contracting ☐ Other, please state: _____

3. Project's contract type:

- ☐ Lump sum ☐ Unit price ☐ Other, please state: _____

Please rate the following variables at project organization level for this green building project	Poor=1 Normal=3 Excellent=5				
	1	2	3	4	5
1. Support from senior management	☐	☐	☐	☐	☐
2. Skilled designers	☐	☐	☐	☐	☐
3. Skilled project managers	☐	☐	☐	☐	☐
4. Trouble-shooting	☐	☐	☐	☐	☐
5. Project team motivation	☐	☐	☐	☐	☐
6. Commitment of all project participants	☐	☐	☐	☐	☐
7. Cooperation between architects and engineers	☐	☐	☐	☐	☐
8. Designers involved in construction stages	☐	☐	☐	☐	☐
9. Contractors involved in design stages	☐	☐	☐	☐	☐
10. Strong/detailed plan effort in design and construction	☐	☐	☐	☐	☐
11. Adequate communication channels	☐	☐	☐	☐	☐
12. Effective environmental compliance and auditing programs	☐	☐	☐	☐	☐
13. Effective feedback	☐	☐	☐	☐	☐
14. Advanced machinery and equipments	☐	☐	☐	☐	☐
15. Effective and efficient software development and application	☐	☐	☐	☐	☐
16. Innovative management approaches	☐	☐	☐	☐	☐
17. Innovative technological approaches	☐	☐	☐	☐	☐
18. Innovative financing methods	☐	☐	☐	☐	☐
19. Adequate financial budget	☐	☐	☐	☐	☐
20. Others, please state:	☐	☐	☐	☐	☐

Are there any other important variables for the AEC firms to reduce the environmental impacts of building projects? If so, list them and briefly explain why these variables are so important.

1. _____

2. _____

3. _____

Do you have any other comments? If so, list them down as follows:

Thank you very much for your contribution

Appendix B: Reliability Analysis

1. Project Management Factors

Item-total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item- Total Correlation	Alpha if Item Deleted
P1	65.3611	78.5230	.7031	.8937
P2	65.8333	83.6286	.2911	.9035
P3	65.9722	80.6563	.5009	.8986
P4	66.1944	81.6468	.4873	.8991
P5	66.0556	80.1111	.5461	.8975
P6	65.7222	78.1492	.6111	.8955
P7	65.5833	79.7357	.6047	.8962
P8	66.0278	81.0563	.4499	.8999
P9	66.4444	77.3968	.3974	.9060
P10	65.9722	76.7706	.6999	.8929
P11	65.9444	77.4254	.7830	.8916
P12	66.2500	78.1929	.6920	.8937
P13	66.4722	79.9706	.5237	.8980
P14	66.5000	77.1143	.6220	.8951
P15	66.7778	81.2635	.4066	.9011
P16	66.4722	76.5421	.6080	.8955
P17	66.3056	83.0754	.2843	.9043
P18	66.9167	75.0500	.6981	.8925
P19	66.1944	77.0754	.5964	.8959

Reliability Coefficients

N of Cases = 37.0

N of Items = 19

Alpha = .9023

2. Organizational Factors

Item-total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item- Total Correlation	Alpha if Item Deleted
O1	43.7027	55.2147	.3226	.7445
O2	45.9459	49.7748	.3855	.7476
O3	44.6216	49.9084	.6918	.6571
O4	45.4595	72.3664	.0346	.7432
O5	45.2973	68.3814	.4407	.7190
O6	45.6216	65.7417	.5331	.7080
O7	45.8649	66.3423	.4880	.7114
O8	45.6757	67.1697	.4422	.7154
O9	46.2973	68.3258	.3627	.7214
O10	45.5135	68.3123	.4800	.7179
O11	46.4324	64.0856	.5743	.7011
O12	46.0000	62.9444	.6187	.6955

Reliability Coefficients

N of Cases = 37.0

N of Items = 12

Alpha = .7331

3. Firm's External Relationships

Item-total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item- Total Correlation	Alpha if Item Deleted
E1	29.5676	21.7523	.5307	.8035
E2	29.8649	21.0090	.6159	.7920
E3	29.4595	21.4775	.7386	.7807
E4	29.6216	21.0195	.6086	.7930
E5	29.7027	23.3258	.4463	.8126
E6	29.0270	25.9159	.2359	.8297
E7	30.2432	20.7447	.6091	.7930
E8	29.9730	23.6381	.3880	.8193
E9	29.1351	23.0646	.5210	.8047

Reliability Coefficients

N of Cases = 37.0

N of Items = 9

Alpha = .8220